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Cover: Seaweed gathering, probably mid-nineteenth century. Artist unknown. *See page 32.* *(The Bettmann Archive)*

New York Bight I: Ocean Dumping Policies

Aerial image of the New York Bight south of Long Island and east of New Jersey. The feature at right center is an acid dump, mixing with the water as it spreads. Also evident is a large outflow of sediment from the Hudson River, filling lower New York Bay and moving eastward through Ambrose Channel and beyond Sandy Hook, New Jersey, almost to the acid dump. The image was produced from a scanner being tested aboard a U-2 aircraft at about 60,000 feet (on July 22, 1974) for use on a pollution-monitoring satellite scheduled for launch in 1978. (NASA)

by Richard T. Dewling and Peter W. Anderson

In the history of environmental protection, concern for the ocean is relatively new. Before passage of the Marine Protection, Research, and Sanctuaries Act on October 23, 1972, there were few direct legal controls on dumping wastes at sea. The preceding major federal water pollution control bills, particularly the Amendments of 1970, were concerned only with oil pollution in marine waters, and pollution resulting from exploration and exploitation of natural resources.

Traditionally, minimal technology has been directed to the waste end of the product cycle. Scientists have confined themselves to finding a "hiding place" for spent wastes and materials. For those industries and municipalities hard pressed by the increasingly more stringent requirements contained in new air and water pollution statutes, and the lack of suitable facilities for land disposal, the ocean offered the ultimate "sink" for the most persistent municipal and industrial wastes.

Certainly, the obvious size and assumed mixing properties of the ocean led many to believe that here lay the supreme "dilution basin." Even our record keeping reflected more national concern to prevent navigation hazards than to safeguard the ocean and its resources. In short, we knew and cared very little about what was being discharged or dumped into the ocean.

In 1968, the first year anyone really bothered to attempt an overall assessment of the volumes and types of materials being dumped into the ocean, it was conservatively estimated that 63 million metric tons were discharged annually. Of this total, 53 million metric tons were dredged materials, one-third of which was polluted; 4.7 million metric tons were industrial wastes; 4.6 million metric tons were sewage sludge contaminated with toxic materials, including heavy

metals; and 0.5 million metric tons were construction and demolition debris. Although the 63 million metric tons constituted less than 2 percent of the annual solid waste volume generated in the United States during 1968, its growth potential was extremely large.

Projected on the basis of trends and coastal population growth, and the potential diversion to the ocean of wastes that may result from the application of tougher water and air quality standards, the volume of wastes dumped at sea could, without regulation, double by 1980. This projection does not include an increase based on per capita consumption rate of materials—a most important factor in gauging the rate of waste production, and one which, in many cases, far exceeds that of population growth. For example, industrial production is increasing at nearly 5 percent, or three times the population growth rate.

Although the total number of ocean dump sites approved by the U.S. Environmental Protection Agency (EPA) has declined from almost 250 to fewer than 150, the ratio of sewage sludge (a by-product of waste water treatment) to industrial waste to be ocean dumped continues to increase. Pollutant concentration levels, particularly with regard to heavy metals, also have risen. It is important to recognize—from a biological response standpoint—that the concentration of materials being dumped is as important as, and in some cases may be more important than, the total quantity of wastes being discharged.

New York Bight: 80 Percent of the Problem

In the continental United States, approximately 80 percent of all ocean dumping, via vessel, of municipal sewage sludge, acid wastes, and industrial wastes takes place off the coasts of New York and New Jersey at six discrete dump sites (Figure 1). The New York Bight, a 50,000-square-kilometer area from Cape May, New Jersey, to Montauk Point, New York, and about 190 kilometers seaward to the edge of the continental shelf, is the site of the largest U.S. ocean dumping program.

The dumping of sewage sludge in the Bight began approximately 50 years ago, while that of industrial wastes started in the late 1950s. The overall upward trend in ocean dumping (Figure 2) is expected to continue, pending the completion of land-based treatment facilities and/or the implementation of environmentally acceptable alternatives for handling these wastes. A review of the volumes dumped in 1974 (Figure 3) reflects the severity and magnitude of the pollution problems in the New York Bight. For example, the amount of sewage sludge alone that was dumped in the Bight in 1974 would cover the 3400 square meters of New York's Central Park to a height of 1.2 meters.

Federal Action

Nationally, EPA became active in ocean dumping activities with the passage of the Marine Protection, Research, and Sanctuaries Act. This legislation, summarized in Figure 4, assigned specific functions to EPA, as well as the Coast Guard, the Army Corps of Engineers, and the Department of Commerce, namely the National Oceanic and Atmospheric Administration (NOAA). In general, the EPA administers and enforces the overall program; administration involves the issuance of dumping permits to municipal and industrial applicants, the evaluation of alternative means of handling wastes, and the selection and management of dump sites. The Coast Guard carries out police-type monitoring of sites, making sure that vessels dump at the proper location and in accordance with EPA permit conditions. Administration of dredged materials and the issuance of permits for their disposal is the province of the Army Corps of Engineers. Finally, NOAA is responsible for conducting research on long-term effects of dumping (see page 11) and for identifying and establishing marine sanctuaries or areas where no dumping should occur.

Regional Commitment

Unquestionably, implementation of the Act on April 23, 1973, spurred EPA's Region II, which covers the New York-New Jersey area, into greater involvement in ocean dumping in the New York Bight. However, there was a great deal of activity and concern even before the enactment of this legislation. For example, since 1971 approval of a construction grant for waste water treatment plants was contingent upon the grantee's abandoning ocean dumping when a more desirable disposal method became available through the efforts and/or requirements of EPA, state, and regional authorities. In June 1972 Region II funded a 4-year investigation by the Ocean County Sewerage Authority, the New Jersey State Department of Environmental Protection, Rutgers University, and the U.S. Geological Survey on the

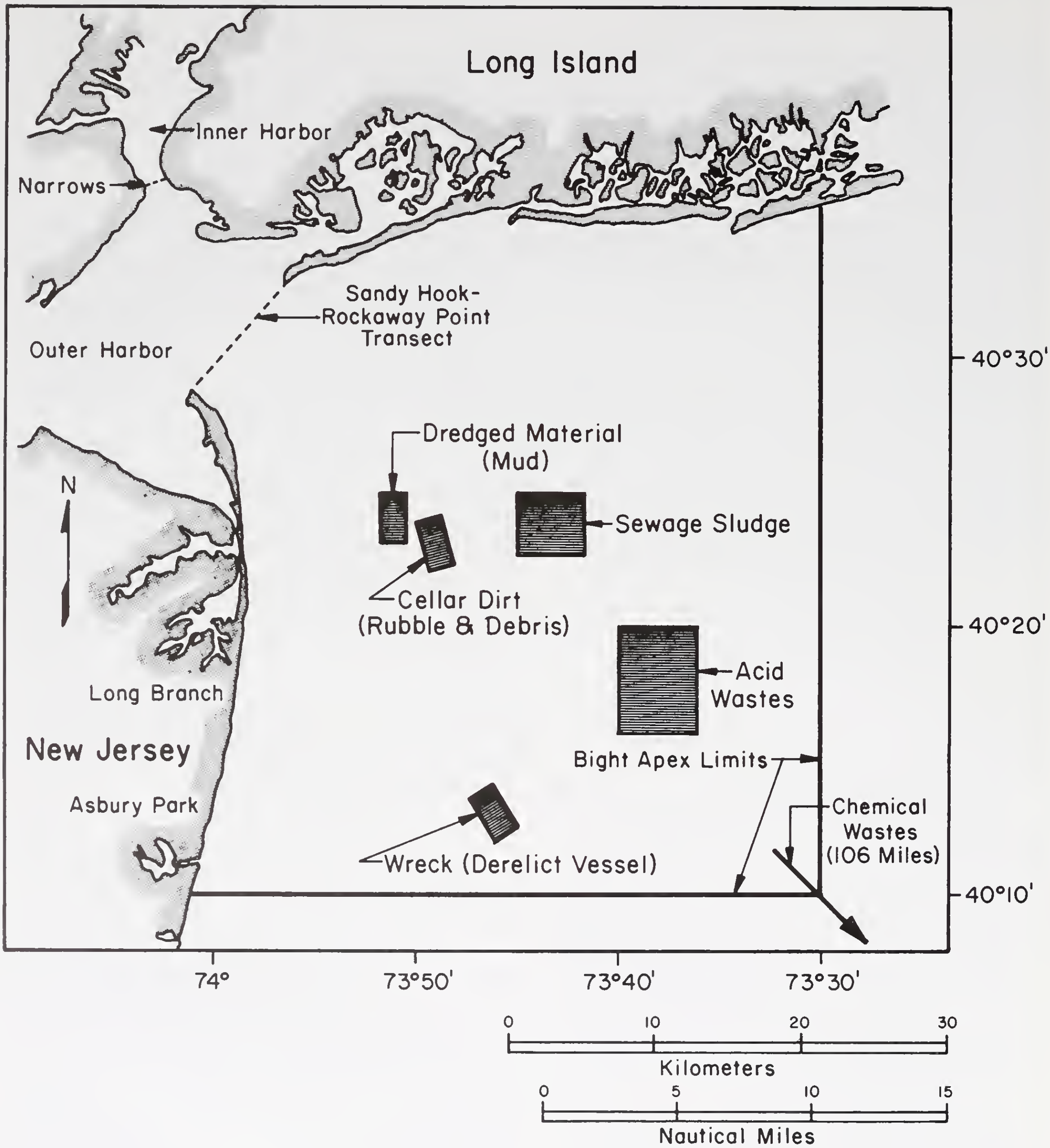


Figure 1. New York Bight Apex and existing dump sites.

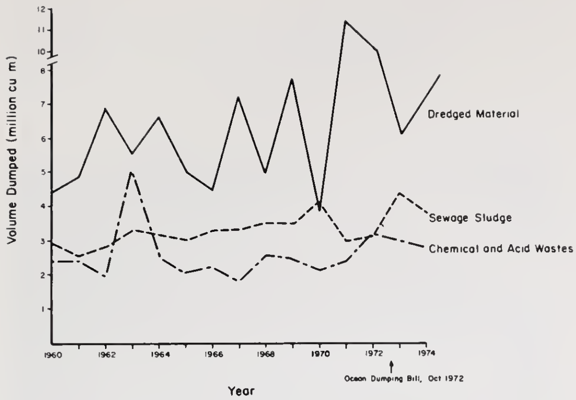


Figure 2. Waste dumping in and adjacent to the New York Bight.

land application of sewage sludge to increase productivity in the relatively sterile soils in the southern New Jersey Pine Barrens (Figure 5). This study is providing useful data on increased vegetal productivity for wildlife management and on the potential environmental problems associated with percolation of nutrients and heavy metals into ground waters. Such information is needed to make a sound decision about the protection of potable ground-water supplies in Long Island and southern New Jersey in the event that land application becomes a desirable method of disposal.

The overall administration of this program has been directed toward meeting the intent of Congress, that is, the ultimate phase-out of environmentally harmful ocean dumping practices. In order to meet its responsibilities, Region II implemented a series of programs, summarized below, with the stated goal of phasing out all industrial and municipal dumping by 1981.

Dumping Permits and Alternative Studies

Promulgation of EPA's interim regulations in April-May 1973 for the transportation and dumping of material into ocean waters was the basis for Region II to develop its permit program. Initially, dumpers were identified according to the quantity and types of waste being handled. Site visits were then made to determine each dumper's immediate need for continuing this practice and the availability of environmentally acceptable alternatives. Based on these visits, forty-seven industries were immediately required to phase out ocean dumping. Where alternatives were not readily available, industries were issued permits that required all liquid wastes, except acid wastes (which are dumped 15 miles offshore), to be dumped at the chemical wastes site 106 miles offshore. Before this decision, most of the industrial wastes were dumped at the sewage sludge site only 12 miles offshore. Furthermore, *it is important to recognize that Region II has issued permits only to municipalities or industries in the New York-New Jersey area that were ocean dumping before 1973.*

Permits to those dumpers without immediately available alternatives were issued in April 1974 under final regulations promulgated in October 1973. Issuance of these permits required that the dumpers submit detailed engineering reports outlining alternatives to their current practice of ocean disposal and establish an approved schedule to implement an environmentally acceptable alternative. In addition, the permittee was required to submit every month physical, chemical, and biological data needed for technical/environmental impact assessment. No such requirement existed before the Act went into effect.

Since initiating the permit program in April 1973, Region II has received requests from 134 applicants. There are also many potential applicants that, because of the requirements, were discouraged from making formal application.

Within Region II, the permit process, which includes an annual public review of information furnished by the applicant, has been effective in moving toward ultimate phase-out. At the most recent industrial public hearing in June 1975, 15 additional industrial dumpers, representing an annual "permitted" volume of 143 million liters, or 15 percent of the "permitted" chemical wastes, phased out their ocean dumping, mainly in accordance with permit conditions. An additional 4 industries, with an annual "permitted" volume of 140 million liters phased out dumping activities by December 1975. The public also was informed at this hearing that implementation plans agreed on by EPA and the industries will result in the complete phase-out of dumping by all but 6 industries by July 1, 1977. The remaining 6 are scheduled to implement alternatives or bring their

$>$85% of all municipal sludges dumped in U.S. via vessels (3,723,000 cubic meters)

$>$65% of all industrial wastes dumped in U.S. (2,720,000 cubic meters)

$>$90% of all acid wastes dumped in U.S. (2,272,000 cubic meters)

Figure 3. Volumes of wastes dumped in the New York Bight in 1974.

Title I. Permits for Ocean Dumping

A. Prohibitions: Transportation and dumping of chemical, biological, and radiological weapons, and of high-level radioactive wastes; transportation and dumping of all other materials unless allowed in a permit.

B. EPA permits cover: Transportation from U.S. for dumping anywhere in oceans; transportation from anywhere for dumping by U.S. Government; dumping in territorial sea, contiguous zone.

C. Administrator will establish: Categories of permits including general recommended sites, times prohibitions on sites, times.

D. Basis for permits: Activity must "not unreasonably degrade or endanger" *human health, amenities, and marine environment.*

E. Criteria must encompass: Need for dumping; effect on health and welfare, shore and beach, marine ecosystems; persistence and permanence; appropriate locations and methods, effects on alternate uses.

F. No permits issued if: Effects on navigation would be adverse; artificial islands would be created; water quality standards would be violated.

G. General provisions not covered: Effluent from outfalls; vessel wastes; oil; materials covered under other laws; fixed structures. artificial islands, articles placed in water, in or on sea bed (not for purposes of disposal).

H. Enforcement: Civil penalty $50,000 per violation (day); criminal penalty $50,000 and/or one year in prison, and revocation or suspension of permit; no penalty for emergency dumping (when needed to save lives).

I. Corps of Engineers permits for dredged materials: Need (effect of denial on navigation, commerce, etc.); other possible means; locations. *No permit unless EPA consents.*

J. State involvement: May propose criteria for dumping in ocean within its jurisdiction or in ocean outside its jurisdiction when its waters would be affected; may propose and implement regulations if EPA approves (EPA issues permits).

Title II. Commerce Department Annual Reports: Effects of dumping in oceans, tidal waters, Great Lakes; possible long-range effects; minimizing or ending dumping in five years; research, demonstrations, etc.; conduct studies, aid others in conducting them.

Title III. Marine Sanctuaries Commerce Department: Where necessary to preserve or restore these values: conservation, recreational, ecological and aesthetic.

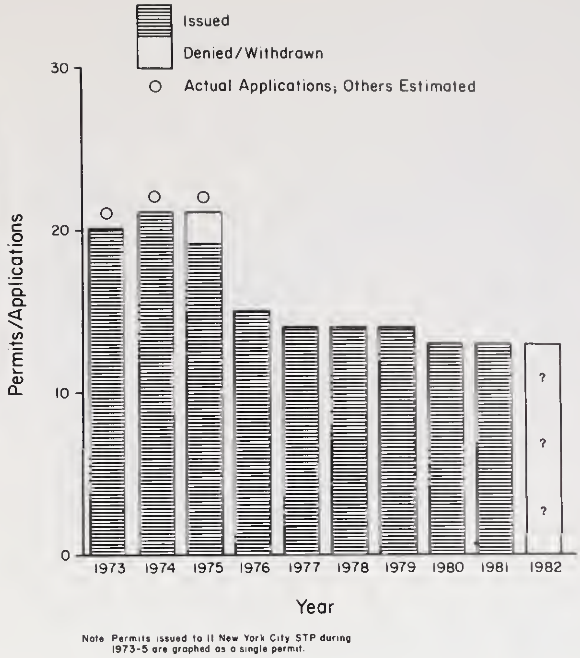
Figure 4. Summary of the Marine Protection, Research, and Sanctuaries Act (Public Law 92-532).

Figure 5. An EPA-sponsored alternative study involves land application of sludge in the Pine Barrens of southern New Jersey. At loadings of 40 tons per acre per year (dry weight), a significant breakthrough to ground-water aquifers has been made with respect to nitrate.

wastes within ocean dumping criteria by 1981. Figure 6 illustrates the status of the municipal and industrial phase-out program established by Region II.

In June 1974, in conjunction with the States of New Jersey and New York, a program was initiated for the development of land-based alternatives to ocean dumping of municipal sludges in the New York-New Jersey metropolitan area. Accordingly, all municipal ocean dumping permittees in the metropolitan area are required either to participate in the sludge disposal management plan developed by the program or to devise their own alternative disposal method. The Interstate Sanitation Commission, a tri-state pollution control agency, was assigned the Region II-funded study to determine feasible and environmentally acceptable alternatives for the area.

The first phase of the study, a technical examination of applicable alternative methods, was completed in June 1975. The report recommended two basic disposal systems for the metropolitan area: (1) filter-press dewatering of sludge (which is about 95 percent water) and incineration, and/or eventual pyrolysis (treatment with very high temperatures) with maximum energy recovery; and (2) land application where sufficient demand exists for a soil-conditioner or fertilizer produced from sludge, and where the application rate amply protects public health and welfare. This Phase I Report concluded that the pyrolysis system could not be implemented before 1985. (More recent information indicates that it could be implemented by 1981.) However, the less favorable alternative, using multiple-hearth incinerators, which could be



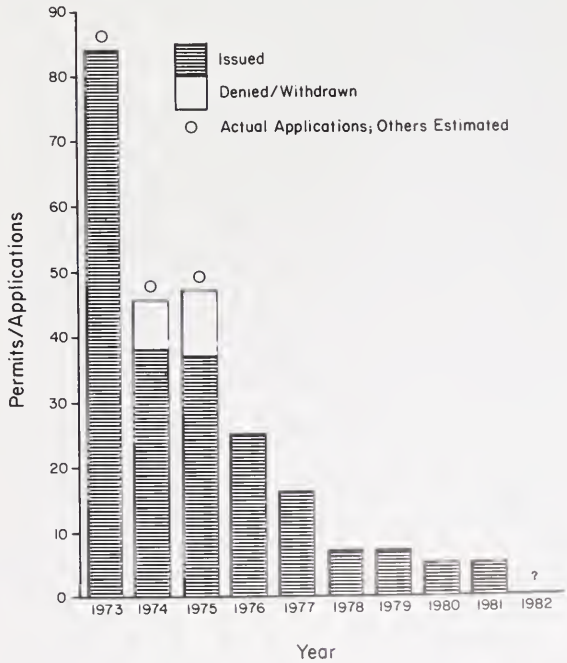


Figure 6. Ocean dumping permits issued for the period 1973-81, municipal (top) and industrial (bottom). (After USEPA, 1976b)

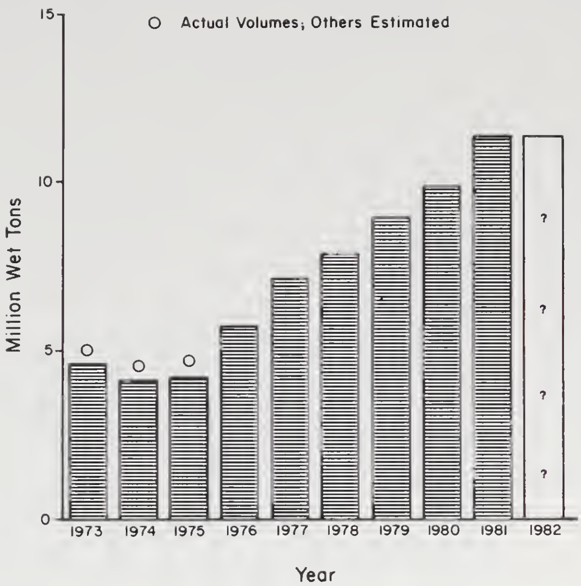


Figure 7. Ocean dumping of municipal sludge, 1973-81. (After USEPA, 1976b)

converted to pyrolysis units, could be implemented by 1981, provided that no major legal-institutional problems develop. Factors considered in this recommendation included environmental impact, economic feasibility, and energy recovery. Current estimates indicate that the implementation of the pyrolysis process would cost about one-half billion dollars. The Phase I Report also recommended that a small-scale, pilot study of pyrolysis be started immediately to develop engineering design parameters needed prior to full-scale demonstration. Such a one-year study, to be funded this fiscal year, will be conducted at an existing pyrolysis plant located in Belle Mead, New Jersey. It is anticipated that useful data will be available four months after the contract is awarded.

Phase II, which is scheduled for completion in July 1976, will provide an in-depth evaluation of the environmental, economic, and technical aspects of alternatives recommended in Phase I. Site locations, capital and operating costs, energy recovery, and an environmental impact assessment will be established in a technical plan for regional sludge management.

A third phase also underway and scheduled for completion in July 1976 will develop the legal and institutional arrangements for the authorization and administration of the operating program identified in Phases I and II.

The completion of this three-phase comprehensive study will provide the framework for implementation of a sound program of land-based alternatives to ocean dumping of sludge in the metropolitan area. In order to continue our policy of maximizing public participation in the Region II ocean dumping decision-making process, we plan to assess the environmental and economic trade-offs associated with any proposed actions.

Evaluation of Environmental Impacts

Early in the Region II ocean dumping program, an assessment was made of future needs and problems associated with the handling of municipal sludge in the New York-New Jersey metropolitan area. It became clear that the construction of new and improved waste water treatment facilities authorized under Public Law 52-500 and scheduled for completion between 1977 and 1980 would increase threefold the amount of sludge that required ocean dumping (Figure 7). EPA, along with NOAA, recognized the potential environmental problems in handling this significant increase in volume at the existing sludge dump site, particularly the potential adverse impacts on coastal water quality along Long Island and New Jersey.

Thus, in late 1973, EPA, with the cooperation of NOAA, began to consider the possibility of designating an alternate sludge dump site for use pending development and implementation of alternative disposal methods. These early efforts resulted in the development of criteria for selecting a new site. In general, they included the following considerations: on-shelf dumping should be considered because of the unknown environmental risks associated with off-shelf dumping of solids; due to economics and logistics the new site should be no more than 65 nautical miles from the harbor entrance; location of a new site should minimize the chance of contamination reaching any beaches; and the site should minimize, to every extent possible, any adverse effect on living marine resources.

Based on these criteria, two potential dumping areas were chosen (Figure 8), each covering an area of over 520 square kilometers. In early 1974 field and laboratory studies were initiated—primarily by NOAA, but augmented by the Raytheon Company under EPA contract—to obtain the physical, chemical, and biological data necessary to assess the environmental impacts of ocean dumping at sites within these two areas. In December 1974 Dames & Moore, an oceanographic-environmental consulting firm, was contracted to prepare an environmental impact statement (EIS) on sewage sludge dumping in the New York Bight. This EIS evaluated, based on *all* available data, the

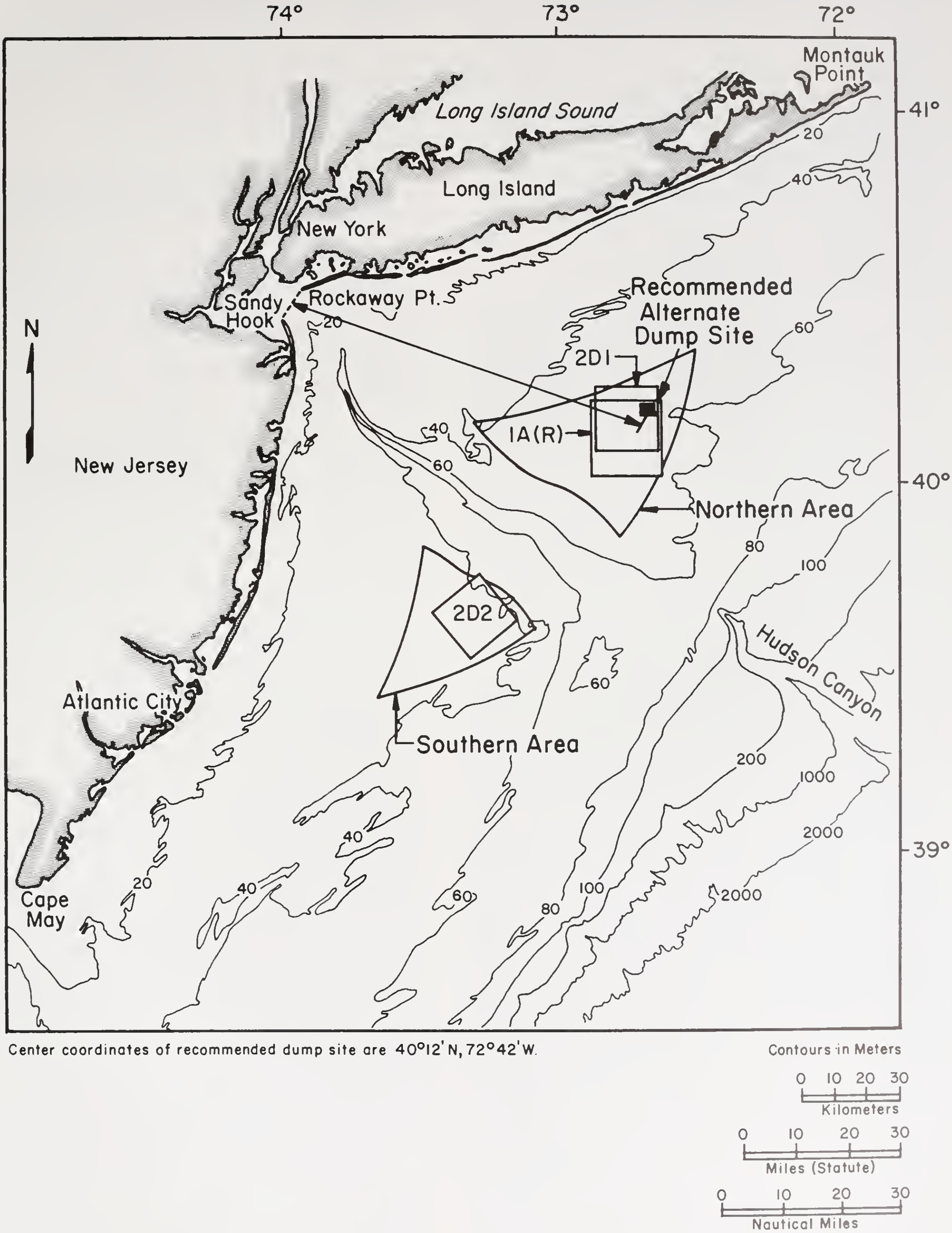


Figure 8. Two potential dumping areas and the recommended alternate site. (After USEPA, 1976a)

potential environmental, economic, and social impact of sewage sludge dumping. Alternative actions (such as land-based methods), continued use of the existing site, or designation and use of a new site were considered. The Draft EIS, released in February 1976, recommends that the existing sewage sludge dump site continue to be used for disposal of current volumes of municipal sludges; an alternate dump site be designated in the Northern Area (Figure 8) for potential use; and an expanded monitoring program and review process be developed to determine when and if environmental factors indicate that the existing site be phased out or abandoned.

The Prognosis

While it would appear that agreement has been reached for phasing out most industrial dumping by 1981, we have not yet resolved the problem of handling, in an environmentally acceptable manner, the projected threefold increase in sewage sludge before alternatives become available. The EIS adequately responded to the question of *where* to put the increased volumes; however, it could not be expected to answer the question of *when*, if at all, it will be necessary to move the site. This decision must be made by EPA, based on a thorough evaluation of the scientific data and environmental conditions at the dump site and adjacent waters. However, herein lies a major problem: What technical, economic, political, and social criteria, alone or in combination with each other, should EPA use in making this decision? Add to this the "time-scale difference"—discussed by Dr. Gross in the next article—between the availability of scientific data and the need for making an immediate administrative decision.

It must be clearly recognized that handling sludge—a waste product that has no public acceptability—involves some form of environmental trade-off. No matter what method is used—landfill, incineration, pyrolysis, recycling, ocean dumping, lagooning, or placing on sand beds—*some* environmental impact will result. The underlying concern in selecting a particular alternative is to minimize the impact. We do not now live, nor have we ever lived, in a world of zero risk; rather, we attempt, as scientists or administrators, to reduce to a reasonable minimum those risks over which we have control. Thus teamwork, between the scientist, administrator, and public, is needed to resolve, in an environmentally acceptable manner, the pollution problems in the New York Bight. Polarization, a condition that presently exists between these three interest groups, can only hinder attainment of the common goal—a safer and cleaner environment. To echo Dr. Gross, there is an immediate need for improving communications between these "communities," particularly on the subject of the New York Bight, for we cannot afford another public display of technically unsupported claims and predictions about a "sludge monster" rising from the deep to engulf the beaches of Long Island.

Recent reports in the news media about the washing up of sludges on Long Island beaches (for example, *New York Times,* 6/24/76) are prime examples of such claims. What has been reported as raw sewage or sewage sludge was, in fact, burned wood, plastics, paper, oil and grease, and other floatables that resulted from inland runoff, pier fires, storm water overflows, and other similar incidents in the New York Harbor complex and its vicinity.

Richard T. Dewling is director of the Surveillance and Analysis Division and Peter W. Anderson is chief of the Marine Protection Program at the U.S. Environmental Protection Agency, Region II, New York.

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New York Bight II: Problems of Research

by M. Grant Gross

Since about 1890 the coastal ocean off New York City known as the New York Bight has provided a convenient and inexpensive means of waste disposal. But in recent years, due to increasing volumes of waste and conflicts over the use of this valuable ocean resource, scientists and policy makers have begun to study the impacts of man's activities on the Bight.

Into this 50,000-square-kilometer area, which includes the continental shelf south of Long Island and east of New Jersey, go the municipal and industrial wastes of almost 20 million people. These materials enter the Bight through the Hudson River system, sewer outfalls, land runoff (including leaching from landfills), and even atmospheric fallout. In addition, huge volumes of wastes are barged out from the New York-New Jersey metropolitan area (see page 3) for disposal at sea (Smith and Brown, 1971). In 1974 the New York Bight received 93 percent of all wastes (except dredge spoils) dumped in U.S. coastal waters (EPA, 1975).

The waters of the New York Bight, however, offer more than a dumping ground. They are heavily used for commercial and sport fishing and shellfishing, swimming, boating, and shipping. Future demands on the area may include tanker terminals, floating nuclear power plants, artificial islands, and sand and gravel mining.

In an attempt to understand the effects of present and proposed activities on the natural processes of the New York Bight, the National Oceanic and Atmospheric Administration (NOAA) is sponsoring a study of ocean waste disposal in the area. Begun in 1973 and scheduled for completion in 1980, the Marine EcoSystems Analysis program (MESA) enables scientists from universities and from private and government organizations to investigate long-term interactions between various oceanographic processes and the volumes of wastes entering the Bight, with a view toward establishing environmental baselines, developing monitoring programs, and providing information on which public policy decisions can be based.

The results of the MESA studies and those of other agencies over the years are reported in the New York Bight atlas monographs, bibliographies (Ali et al., 1973; NOAA, 1974), and symposium proceedings (Gross, 1976). Below are some of the highlights of this research in the most urbanized segment of coastal ocean in the world, a highly stressed environment where scientists are being challenged to provide answers for resource management and conservation.

Bottom Sediments

Alteration of the New York Bight as a result of waste disposal is most easily documented on the ocean bottom. There the solid wastes have accumulated, changing the local topography, altering physical and chemical characteristics of the bottom, and affecting the nature and abundance of bottom-dwelling animals near the disposal sites.

Between 1888 and 1973 about 250 million cubic meters of waste solids—primarily dredged materials—have been dumped in the New York Bight, about 88 million cubic meters between 1963 and 1973. S. J. Williams and D. B. Duane (1974) of the Coastal Engineering Research Center showed that waste deposits have filled the innermost reaches of the submerged Hudson Shelf Valley and formed hills on the ocean floor up to 15 meters high. Accumulations of sewage-derived solids may also have altered sediment properties in the head of the Hudson Shelf Valley, but there is no evidence of major accumulations, indicating either decomposition or removal by currents. Little or no natural sediment reaches the area to bury these wastes.

The distributions of fine-grained waste deposits change seasonally. Whether these carbon- and metal-rich deposits are moving toward the beaches has been a major issue. Changes in distribution of carbon-rich muds, studied by W. H. Harris of Brooklyn Colllege of the City University of New York, were most obvious near

The U.S. dredge Goethals *preparing for work in the Hudson River. Large amounts of sediments dredged from river channels and harbors come from erosion of agricultural areas and land left bare during construction work. Dredged materials mixed with sewage solids and industrial wastes are generally unsuitable for landfill and are usually dumped at sea. (U.S. Army Corps of Engineers)*

Long Island beaches and in the northernmost part of the Hudson Shelf Valley. Near Long Island, mud patches were most extensive during late spring and summer; they were absent, covered over by sands, or restricted to troughs between sand waves from early fall to early spring. Ages of organisms living in these muds indicated that individual patches had existed within a few kilometers of the Long Island shore as early as 1972. Mud accumulations in the Christiaensen Basin also apparently moved toward the shore during some months and retreated during others. Source identification of fine-grained muds, including sewage solids, has been unsuccessful and must await more definitive investigations.

From other investigations there was no compelling evidence that these fine-grained materials are moving onto the beaches in large quantities, even though they move seasonally in response to changing conditions in the Bight. Thus the issue remains unresolved.

Benthic Biological Processes

The deposition of solids from sludges, dredged materials, and other sources has clearly affected bottom-dwelling animals in the New York Bight. J. B. Pearce (1972) reported that two areas totaling about 50 square kilometers were impoverished of normal bottom organisms. Deposits in these areas had high metal and carbon contents, and a finer grain size that resulted in significantly changed bottom characteristics.

More detailed work by Pearce at NOAA's Sandy Hook Laboratory showed substantial year-to-year variability in the number of species and individuals. Some species, such as the crab *Cancer irroratus,* were considerably reduced in number and distribution. But other species, such as the deposit-feeding bivalve *Tellina agilis,* were essentially constant. Such natural variability of organisms in the area makes it more difficult to assess the changes caused by waste disposal.

Waste disposal also affects water quality and the productivity of phytoplankton (minute floating marine plants). In coastal waters phytoplankton production is often limited by scarcity of nitrogen compounds, but in the New York Bight there is abundant nitrogen supplied by estuarine discharge and by decomposition of organic materials on the ocean bottom. Lack of light seems to be the limiting factor in this case. According to G. T. Rowe, K. L. Smith, and C. H. Clifford of Woods Hole Oceanographic Institution, nutrient regeneration and release from sediment deposits in the Bight is of major importance to near-surface biological processes.

Antibiotics and biocides in the wastes also affect microorganisms. L. Koditschek of Rutgers and P. Guyre of the University of New Hampshire reported that approximately 1 percent of the sediment bacteria from areas near the disposal sites were resistant to low levels of mercuric chloride and/or tetracycline. Furthermore, the majority of bacteria isolated from these deposits showed resistance to several different antibiotics. The concern has been expressed that the waste deposits of the New York Bight are causing the evolution of "superresistant" bacteria, with possible public health implications.

Large volumes of construction and demolition debris are routinely dumped in the Bight (see Figure 1, page 4). Land-based disposal of these wastes would cause Manhattan to build up at the rate of about one meter per century. (F. B. Grunzweig, Photo Researchers)

If a large fraction of the organic matter dumped in the Bight can be rapidly decomposed on the ocean bottom, one could argue that disposal of sludges over a wide area is the preferred strategy. But if the wastes simply accumulate or decompose only slowly, then the indicated strategy would be to limit use of the disposal site in order to confine the area where the sediments are physically changed. Oxygen consumption by New York Bight sediments indicates that approximately 20 percent of the daily input of sewage sludge could be decomposed on the bottom. This, by itself, suggests that wide dispersal of sewage wastes on the shelf might be an attractive management option but one that needs further study before it is adopted.

Water Column Effects

The effects of waste disposal on the waters of the Bight are harder to document, primarily because of their renewal by waters from the continental slope. New York Bight waters exhibit estuarine circulation typical of coastal areas where discharges of river water and low-density wastes exceed evaporation. Surface waters move generally seaward above the pycnocline, while near-bottom waters move generally landward. Over the mid- and outer-shelf there are intrusions of relatively saline and warm slope waters, which may be important to the exchange of waters between shelf and slope regions, as suggested by A. L. Gordon, A. F. Amos, and R. D. Gerard of the Lamont-Doherty Geological Observatory of Columbia University.

The time required for currents to replace the waters of the Middle Atlantic region (the continental shelf area between Cape Cod, Massachusetts, and Cape Hatteras, North Carolina) is about ¾ ± ¼ year and is accomplished primarily by the southerly flows at speeds of 5 to 10 centimeters per second, as shown by R. C. Beardsley of WHOI, W. C. Boicourt of Johns Hopkins' Chesapeake Bay Institute, and D. V. Hansen of NOAA's Atlantic Oceanographic and Meteorological Laboratory.

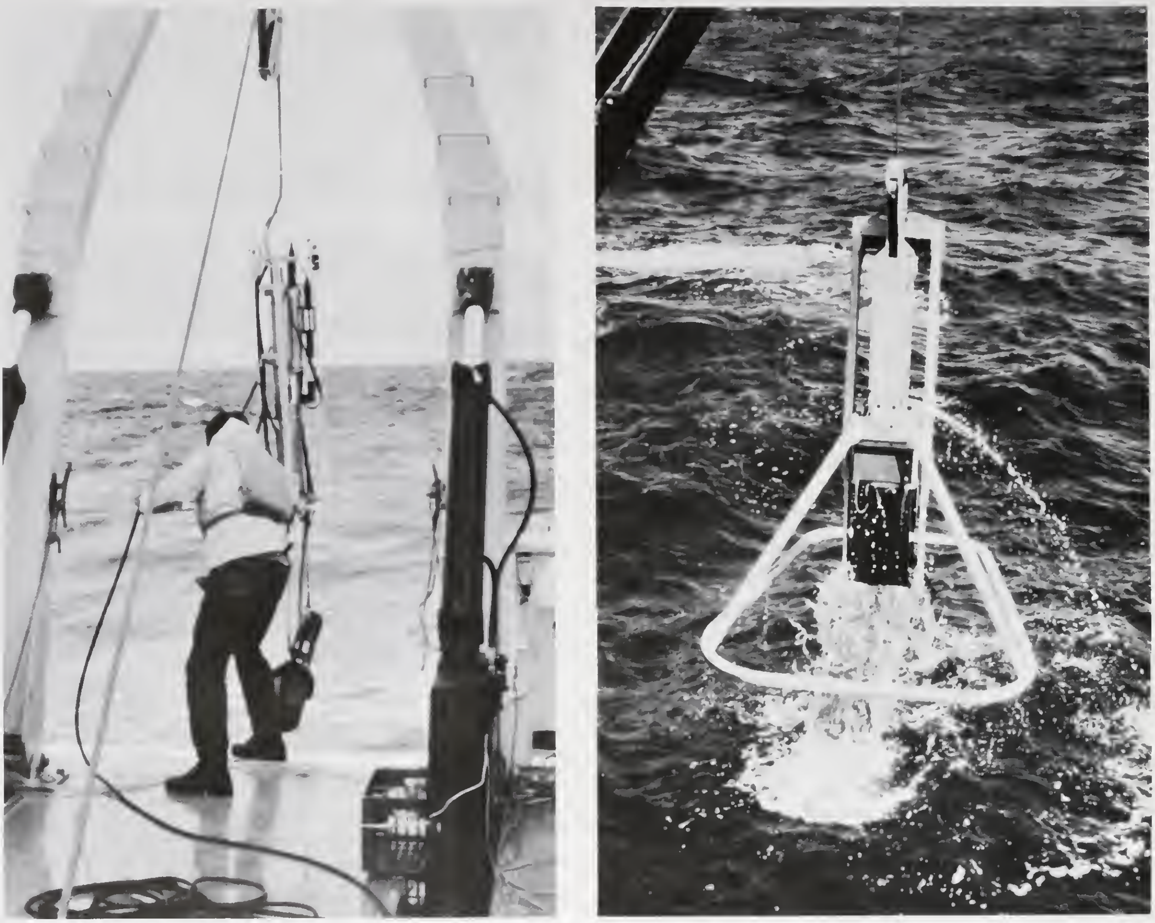
Because of its importance to marine life, the abundance of dissolved oxygen was investigated and the cause of oxygen depletion was studied. D. A. Segar and G. A. Berberian of NOAA's Atlantic Oceanographic and Meteorological Laboratory analyzed sources of oxygen-consuming organic matter to the New York Bight to determine which were major causes of depletion. They reported that decomposition of phytoplankton accounted for most of the oxygen demand in the Bight Apex (see Figure 1, page 4), especially during summer months. Sewage sludge and riverborne organic matter were generally of equal importance.

Municipal solid wastes are not dumped at sea, but some of the street litter becomes storm runoff that enters the harbor and often moves out to sea. (Monroe Pinckard, Photo Researchers)

Seabed oxygen consumption was reported to have little effect on dissolved oxygen concentrations in the region's near-bottom waters. Since the bulk of the dissolved inorganic nitrogen that supports these high levels of productivity is discharged from New York Harbor, Segar and his co-workers argue that river input is the dominant factor causing low dissolved oxygen levels in the New York Bight, especially during summer.

Metals discharged with Hudson River effluents and released from the decomposing waste deposits have been a particular concern in the region. Segar and A. Y. Cantillo studied the metal contaminants (chromium, cadmium, copper, iron, mercury, manganese, and zinc) released to the Bight and concluded that New York Harbor was the main source of dissolved metals, particularly manganese. A large portion of these metals, especially iron and manganese, are lost from the water column during mixing of estuarine and oceanic waters. Metals such as dissolved zinc are released from sludge.

Because of such releases and the estuarine sources, concentrations of cadmium, iron, mercury, and zinc are considerably higher in Bight waters than in waters offshore. Copper concentrations, however,



Research in the Bight: (left) water sampling equipment and sensors are lowered over the side of NOAA's R/V Ferrel; *(right) box corer with sediment samples is taken aboard the NOAA ship* George B. Kelez. *(NOAA/MESA)*

Table 1. Primary productivity of major ocean areas, the New York Bight and adjacent areas.

Ocean Area	Mean Productivity (grams of dry carbon per square meter per year)	References
Open ocean	50	Ryther (1969)
Coastal ocean	100	Ryther (1969)
Upwelling area	300	Ryther (1969)
Peru	475	Guillen et al. (1973)
New York Bight	100-160	Ryther and Yentsch (1958)
New York Bight Apex	370	Malone (1976)
Long Island Sound	280	Riley (1956)

were found to be nearly uniform.

Productivity

Low nitrogen concentrations are generally considered to be the limiting nutrient in coastal waters. Nitrogen in several forms is contributed to the New York Bight by the estuarine discharge carrying nitrogen derived from upriver and harbor sources and by the waste disposal operations, especially the dumping of sewage sludge. Thus, waste discharges should stimulate phytoplankton productivity.

T. C. Malone of City University of New York found that phytoplankton productivity ranged from a December low of about 0.1 gram of carbon per square meter per day to a June maximum of 6.4 grams of carbon per square meter per day, with a subsidiary peak in February. Most of the dissolved inorganic nitrogen (nitrate + nitrite + ammonia) was consumed by phytoplankton within 30 kilometers of the mouth of the estuary. Annual phytoplankton production amounted to 370 grams of carbon per square meter per day in the 600-square-kilometer area nearest the harbor entrance (Table 1), which is about the same as that for Long Island Sound. In short, the New York Bight is not a "Dead Sea" but responds to the high nutrient concentrations from sewage discharges in the harbor by supporting levels of productivity higher than normal for coastal ocean regions, outside of upwelling areas.

D. A. Segar and G. A. Berberian showed that the supply of dissolved inorganic nitrogen from the estuary exceeded phytoplankton demands, except during June, July, and August, when estuarine discharge accounted for about 60 percent of the demand. Ocean disposal of sewage sludge and dredged materials could have provided a maximum of 10 percent of the summer nitrogen demand. It appears that phytoplankton productivity was light-limited in the Apex. Disposal of sewage sludge and dredged wastes had no statistically significant effect on phytoplankton growth rates or on the factors regulating these rates.

Finfish and Fisheries

The New York Bight and adjacent waters have been fished extensively, especially for ground fish between Georges Bank and Cape Hatteras. R. L. Edwards of NOAA's Northeast Fisheries Center showed that about 22 percent of the available finfish fishery resource was harvested from 1963 to 1965. Between 1964 and 1967, standing crops decreased about 40 percent, indicating that the ecosystem was probably being harvested at or near the maximum rate.

A normal winter flounder, Pseudopleuronectes americanus *(top) and one with fin rot taken from a sludge-affected area of the New York Bight. Although the pathogenesis of fin rot in wild winter flounder is unknown, preliminary studies by Murchelano and Ziskowski indicate active fin rot lesions on winter flounder kept in cages in the sewage sludge area of the Bight. (Photos courtesy of R. Murchelano)*

Because of intensive fishing in the region, the standing crop of commercial finfish and squid has declined dramatically, more than 50 percent since 1967. These declines are attributed primarily to heavy fishing and have no obvious relation to waste disposal in the Bight.

Locating areas of minimum risk for new waste disposal sites or offshore petroleum production or transfer facilities is difficult because of wide overlaps in the density distributions of most species. M. D. Grosslein of NOAA's Northeast Fisheries Center concluded that it is virtually impossible to find a location in the New York Bight where a significant aggregation of some major species does not occur at some time during the year.

Some of the localized effects of waste disposal were unexpected and required a great deal of study to document. Fin rot—progressive destruction of fin tissue—in winter flounder *(Pseudopleuronectes americanus)* was found to be appreciably higher in the heavily used Apex than in adjacent coastal waters. R. Murchelano and J. Ziskowski of NOAA's Sandy Hook Laboratory, Middle Atlantic Coastal Fisheries Center, found that fin rot was not restricted to the New York Bight

Apex but also occurred in fish taken from Raritan Bay, a nearby polluted estuary. Fish may contract fin rot during their time in the degraded areas; some fish, summer flounder *(Paralichthys dentatus),* for example, may contract the disease while passing through contaminated areas during migration.

Fin rot in winter flounder is apparently not a rapidly progressive or fatal disease. But it may modify behavior and render fish more vulnerable to predation or reduce their ability to capture prey.

Chlorinated hydrocarbons and some common industrial metals (lead, silver, cadmium, chromium) are known chemical mutagens, and significant genetic damage can occur at subtoxic levels. A. Crosby-Longwell of NOAA's Milford Laboratory, Middle Atlantic Coastal Fisheries Center, studied chromosomes and mitoses during genetically sensitive and critical stages of the second half of meiosis, fertilization, cleavage, and embryo divisions to see if eggs from a single population of mackeral from the New York Bight showed any evidence of abnormalities. Of 380 eggs collected during May 1974, and analyzed, one-third showed abnormalities. In only one-fifth of the eggs were all chromosome and divisions figures scored normal. The abnormalities showed the same sort of damage expected to follow irradiation. Comparable levels of abnormalities were observed in mackerel eggs from the periphery of the Bight (13 to 16 percent). Samples from two stations in the toxic chemicals disposal site ("106-mile site"; see Figure 1, page 4) showed the highest level of abnormalities; it was the only location where a significant number of dead eggs were found. This important subject requires further field and laboratory study before we can understand its significance.

In brief, several of the region's coastal water areas are badly degraded, the New York Harbor and New York Bight being well-known examples, but there are large, relatively uncontaminated stretches of coastal water where C. J. Sindermann of NOAA's Sandy Hook Laboratory found little or no evidence of human impacts. And there was little indication of widespread damage to major fisheries resource populations resulting from pollution of coastal waters. Other factors such as repeated year-class failure (or success), shifts in population distributions, and overfishing may cause pronounced changes in fisheries.

Public Health

Public health is the bottom line of any environmental study. Conflicting uses of the New York Bight and their potential public health implications emerged early in the studies of the area. But surprisingly, relatively little data are yet available on the complex of possible transfer mechanisms between the wastes entering the Bight and the populations that use or live near the shore.

Present research in the Bight arose from concerns of Public Health Service officials about risks involved in harvesting surf clams (*Spisula solidissima*) from waters off Long Island and New Jersey. These studies, begun in 1962, resulted in closure of areas around the sludge disposal sites to shellfishing. Since then other continental shelf areas off New York, Delaware Bay, and Boston Harbor have been closed to commercial shellfish production where sewage sludges or effluents from sewage treatment plants are discharged to coastal waters.

V. J. Cabelli and co-workers at the U.S. Environmental Protection Agency's National Marine Water Quality Laboratory studied 9300 weekend swimmers exposed to the relatively unpolluted waters at the Rockaways (Riis Park) and the barely acceptable waters at Coney Island near 22nd Street on Long Island's south shore. The incidence of gastrointestinal symptoms (vomiting, diarrhea, nausea, or stomach ache) among swimmers at the Coney Island beach was significantly higher than that among nonswimmers. This was not the case at the Rockaways beach. The most sensitive portions of the tested population were children and Latin Americans.

Institutional Constraints

The results presented here have been selected from publications spanning decades of research, including the pioneering studies of H. B. Bigelow and B. H. Ketchum of WHOI during the 1930s and 1940s. Because of greatly increased funding beginning around 1970, much of the work is less than five years old. This, in part, accounts for the spotty coverage of important topics, such as public health, and incomplete results in other fields. Some of these gaps will be closed with time. Nevertheless, further increases in funding would permit better coverage of topics, more sampling, and generally improved studies.

There are other problems and institutional mismatches that plague any effort to apply scientific results to societal problems. For example, it is no surprise that scientists do not communicate well with administrators, politicians, and judges. This has been a particular problem in the New York Bight studies, and it is therefore worthwhile to examine some of the causes of frustrations for both

scientist and policy maker.

Evaluating the impacts of waste disposal operations requires sound answers based on detailed information. But gathering the information to provide reliable answers requires time, and no programs have yet gone on long enough or been adequately funded. The problem is the time-scale differences for oceanographic research and for federal agency funding.

Research programs typically require several years of planning before full funding can be obtained through agency budgetary procedures. Thus, projects inevitably get off to a slow start. Also, oceanographic research involves a year or more of preliminaries in gathering ships and other support facilities. Then at least three years of field work are necessary in areas where there are seasonal changes, in order to make reliable estimates of annual and seasonal variability in biological phenomena. Finally, with that amount of data, a one- to two-year period is required to complete the analysis. In all, it takes five or more years, from the beginning of full operations, to understand the processes one is dealing with. Some preliminary observations are usually available sooner, but many oceanographers do not consider their results definite with less than a full set of data and object to pressures for "quick and dirty" answers that delay completion of better-documented results. In the case of fisheries research for the Middle Atlantic shelf, more than a decade was spent in gathering and analyzing the data, and still it is impossible to separate completely natural variability from changes caused by intense fishing.

Thus, the scientist wants the best data fully analyzed before a decision is made; the administrator must use what is available to solve the immediate crisis and resents the scientist's reluctance to give answers. And then there is the congressman who expects simple, direct answers and is annoyed to hear "on the one hand . . . and on the other hand . . . "

The long time required for scientists to complete an investigation to their satisfaction gives rise to another frustration. The mission of the research group or the source of funding may well change before the project is completed, and the scientist must take up some other function. This causes morale problems for members of the scientific staff, who have made personal commitments to a project they cannot complete. Frustration mounts when another scientist, working on the same or a related problem, then requests the data. The first scientist is likely to feel that someone has run off with his "baby."

Public health is the major concern of scientists and administrators involved in studies of the New York Bight. The temporary closings of some Long Island beaches this summer fueled the ongoing controversy over the sources and fates of various pollutants in New York Harbor and coastal waters. The poor understanding of natural dynamic processes in the Bight makes the assessment of human impacts all the more difficult. (Fritz Henle, Photo Researchers)

There is also the problem of modes of communication. A scientist usually prefers a scholarly publication or a professional meeting as the forum in which to make his work known. Being called on to present results in congressional hearings or court cases is an unfamilar and often unpleasant experience for the scientist, in that much of the attention focuses on procedure at the expense of content.

Earlier research in the New York Bight was traditionally limited by inadequate funding and a lack of proper facilities to carry out detailed programs on the continental shelf. Scientists tended to work on narrowly formulated problems, often ignoring other areas of marine science. Physical oceanographers assumed steady-state conditions and developed box models to indicate the probable flushing times of the shelf waters. Geologists tended to regard sediment distributions as static, having changed little, if any, since the last advance of the sea across the area as the glaciers melted between 18,000 and 3000 years ago. And biologists were mostly concerned with determining what was there and in what numbers—essentially a taxonomic or, at best, an ecological approach. There was basically no exchange of ideas or data among disciplines.

Thus, when policy makers began to ask detailed and interdisciplinary questions about waste disposal, scientists faced a challenge.

Too often scientists tend to speak their own jargon and have little knowledge of the interests, techniques, and prejudices of other scientists. In addition, they have limited contact with administrators, lawyers, and politicians, especially during the early planning and the implementation of research programs. However, through continued interactions on projects such as the MESA program and the Southern California Coastal Waters Research Program (SCCWRP), which has played a comparable role in the Southern California region, scientists and policy makers can begin to bridge the gap.

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CBI Contribution No. 238

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EARLY DAYS OF MARINE GEOLOGY

BY R. S. DIETZ AND K. O. EMERY

We hold no brief for the "good old days" but perhaps it adds to the perspective of marine sciences, and certainly to humor, to recall something of the beginnings of marine geology in the United States by citing some of our early experiences. This subdiscipline of geology commenced almost simultaneously in the mid-1930s on the East Coast at the Woods Hole Oceanographic Institution with the research of Henry C. Stetson and on the West Coast with the studies of Francis P. Shepard. Stetson died at sea aboard *Atlantis* off Chile in 1955, while Shepard is still actively working at the Scripps Institution of Oceanography in La Jolla, California.

We were the first of Shepard's sixty or so marine geology students, shuttling with him between the University of Illinois and Scripps. We met at the University of Illinois, where we arrived via modes of transportation that were the norm for those Depression days. Dietz arrived by hitchhiking from the East Coast; Emery came by train, riding boxcars from San Diego.

In 1936 Shepard received a grant from the Penrose Fund of the Geological Society of America for studying submarine canyons and the sea floor generally off the coast of California. The amount was $10,000, which was a handsome grant for those days—in fact, the largest ever given by the GSA in prewar years. With the money he was able to charter the 96-foot schooner *E. W. Scripps* of the Scripps Institution of Oceanography for six one-month cruises, build the necessary scientific equipment, employ us as his assistants at a salary of $30 per month, and support the abortive development (to the tune of $1,000) of the Varney-Redwine hydrostatic corer. It was hoped that this latter device would outperform the famous C. S. Piggot gun corer, which shot the barrel into the ocean bottom. We should add "in principle," because the Piggot device, when used from *Atlantis*, seemed to obtain cores of equivalent length whether or not the gun actually fired. A subsequent grant provided for three more months in the Gulf of California during the fall of 1940. Since bed and board was provided aboard ship, we both signed on for $1 for the three months to make us official expedition members (but Scripps never paid the $1—perhaps fearing that we'd spend it unwisely). An interesting guideline also was that students should not receive any pay for research that pertained to their own thesis projects.

The low funding at least required us to develop some ingenuity in devising simple, inexpensive instrumentation. For example, we used the 2-meter-long Roger Revelle, later director of Scripps Institution of Oceanography, as a wave staff by having him stand at various distances from shore in the buffeting surf. This rather absent-minded wave staff also was noted for having stepped into a bucket while measuring cores aboard ship and wearing it for a couple of hours. As another example, we organized a rock preparation and sedimentation laboratory for which a budget of $50 per year was arranged. This was considered a reasonable proportion of the Scripps' overall budget of $125,000 per year.

Notably also, Woods Hole Oceanographic Institution was founded in 1930 with a gift of $3,500,000 from the Rockefeller Foundation received over a period of several years; this was sufficient to construct the large brick Bigelow Building and the ketch *Atlantis*, and to cover all operations for ten years. The annual budgets for

The 96-foot schooner E. W. Scripps, *principle research vessel of the Scripps Institution of Oceanography from 1937 to 1950. (Courtesy of SIO)*

the two institutions have remained about equal, nowadays almost $22 million for Scripps and $20 million for Woods Hole.

Life aboard *E. W. Scripps* was somewhat different from shipboard duty today. The ship's crew consisted of only four persons—captain, engineer, deck hand, and cook; the scientific party was seven—the number of bunks available. We generally worked around the clock, six hours on and six off. The scientific party was expected to be sailors to run the ship and technicians to operate oceanographic winches, assemble and use the water and bottom samplers, and do various shipboard analyses for water chemistry. Among our duties while steering the ship was to tabulate by hand the water depth every two minutes. We did this with great enthusiasm since we had installed aboard the latest Submarine Signal Co. fathometer, which indicated the depth on a revolving red-flashing neon light. Graphic recorders had not yet been invented, so this instrument represented to us a remarkable advance over the sounding lead. And, in fact, we continued to use the hand-powered wire-and-lead sounding winch installed on a rowboat for making hydrographic surveys of the inner heads of several submarine canyons. Rather remarkably, it was possible to demonstrate that canyon heads were repeatedly filling with sediment and then emptying out.

Prior to the cruises we built dredges, grab samplers, sediment traps, and corers. The best corer that we constructed was a 600-pound open-barrel gravity model that increased the weight of such devices over earlier models by a factor of ten. We purchased junk lead at 3¢ per pound, used scrap 2½-inch pipe, and built two corers for about $50 each. It was not until after the war that we heard about Kullenberg's invention of the piston corer. Nevertheless, we commonly obtained cores 12 feet long, and in one instance, a diatomaceous ooze core in the Gulf of California 17 feet long for a new record. Of course, things were considerably cheaper in those times. By way of example, an apparently wealthy American tourist at the local swinging bistro named El Tecolote (The Owl) in Guaymas, Mexico, generously offered to buy beer for our ship's staff. When he discovered that the bartender could not change his U.S. $10 bill, he gallantly said, "Set up the whole amount in beer." One hundred and twenty bottles of Carta Blanca were lined up along the bar, and as was customary then in Guaymas, bowls of unshelled shrimp were thrown in like the free peanuts of today. A side advantage was that the long row of beers immediately stopped the girls' pestering us for drinks.

After the cruises, when the ship was unloaded so that the biologists or physical oceanographers could take their turns, we were able to study the samples and other results. Since all was new, both to us and to others, we had no difficulty in finding problems. Our masters' theses were on mechanics of coring and on the extensive phosphorite deposits we discovered covering many of the offshore banks. Our doctoral dissertations were on clay minerals of the deep areas and on rocks of the shallow banks. We recognized that the offshore basement geology of the Southern California borderland belonged to the Franciscan province. Articles on terraces, currents, barite concretions, and transport of rocks by kelp and sea lions were by-products. The overall results were incorporated into Special Paper 31 of the Geological Society of America by Shepard and Emery, a monograph treating submarine canyons and the general bathymetry of the sea floor off California. These must have been our most productive years in terms of variety and number of investigations, because of newness of the field and, probably, the aid of funds too small to permit much diversion of time and energy.

Local transportation was provided by a succession of old cars, starting with a 1928 Chevy that Shepard bought for us for $50. By the time we drove it 15 miles, cork in the transmission wore out and serious noises developed. Replacement by junk gears extended the life of the Chevy for a year or so. After tiring of having to tie a rope around the car to keep the doors closed, we swapped it for a 1928 Reo that had a good engine but bad tires. Eventually, this was swapped for Walter Munk's 1928 Buick (The Queen Mary). The state of the Reo's tires is illustrated by a blowout of the spare tire in the hot California sunshine when he drove northward too long. In time the differential of the Buick disentegrated, and a 1928 Ford was next. The total cost of these four cars was $200–nothing compared to their present value as antiques if they had been stored until now.

Dietz with gravity coring device at rail of E. W. Scripps, *about June 1938.*

Emery with hollow giant worm or animal tube of enigmatic origin dredged from the wall of Dume Canyon off California, May 1938.

The four years of cross-country commuting, cruising (at least 12 months aboard *E. W. Scripps*), and study came to an end in 1941. Just before receiving his doctorate, Emery wrote 135 individual letters, blanketing the entire country, seeking employment. Dietz, being congenitally lazier (or possibly more efficient), trusted that this blizzard of inquiries would produce several plums of which he might select one after Emery made his acceptance. But the market for marine geologists, like the job market for poets then and now, was bleak. Not a single position was tendered. As with many products, there is commonly no demand for the first ones off the line. Even the U.S. Navy saw no particular need to know anything about oceanography; in fact, its interest, when it did develop, probably stemmed from the initiative shown by the Army Air Corps in setting up a group of officers and civilians to predict the paths of downed airmen in their rubber life rafts carried by surface currents of the western Pacific.

In retrospect, the "good old days" were both the best of times and the worst of times. Happily, one tends to recall the ups rather than the downs–and there is no substitute for the bouyancy

of youth. Oceanography of today is, of course, much more sophisticated and the results ever more quantitative. But there was a certain enjoyable simplicity, and even beauty, in working with instruments that had less than one vacuum tube, let alone one transistor. The need to do all kinds of work gave us a broad view of the ocean such that we were oceanographers and not just marine geologists. We even thought we understood physical chemical, and biological oceanography. Working on the low-freeboard *E. W. Scripps* with decks awash gave an intimate feel for the oceans such as experienced today only by scuba divers.

As we write this note Charley Hollister is putting out to sea with his "Super Straw," the giant 4½-inch coring device, and a new generation of marine sedimentologists. They will study complex seabed forms, subbottom acoustically reflecting layers, and mass physical properties of muds. In this work they will be guided by the multisensor MPL Deep-Tow, a real-life dream machine. All in all, a million-dollar effort. Yes, times have changed—and for the better.

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Dietz with sediment trap and Emery and Shepard with wire sounding machine setting one for the survey of La Jolla Submarine Canyon, November 1938.

Antifreezes in Cold-Water Fishes

by Arthur L. DeVries

Approximately 10 percent of the world oceans experience freezing conditions either continually or for at least part of the year. These waters lie primarily in the polar regions, although some parts of the North Pacific and northwest Atlantic are cold enough to freeze during the winter (Figure 1). Despite the extreme temperatures of these areas, animals are present and some are even year-round residents. Marine animals such as seals and whales are in no danger of freezing under these conditions since the temperatures of their bodies are well above the temperature of the waters they inhabit. Likewise, cold-blooded invertebrates such as crabs, starfishes, and isopods will not freeze, because their body fluids have a slightly higher salt concentration than that of seawater. The remaining group of marine animals is comprised of the cold-blooded vertebrates, or fishes, that have neither warm body temperatures nor high salt concentrations in their body fluids and are thus in potential danger of freezing.

Fishes have only about one-third the amount of salt in their body fluids as is present in seawater. This means that the body fluids of temperate marine fishes freeze at approximately -0.7°C, which is 1.2°C above the freezing point (-1.9°C) of seawater. One way that fishes can avoid freezing is to become supercooled. It is well known that water can often be supercooled several degrees below its freezing point. In the absence of ice, most fishes can tolerate a small amount (1 to 2°C) of supercooling, and it appears that the slightly supercooled state is stable enough so that spontaneous nucleation (formation of seed ice crystals) does not occur. Supercooling has been described in several species that inhabit the ice-free deep waters of the arctic fjords. When these fishes are brought to the surface and exposed to ice, they

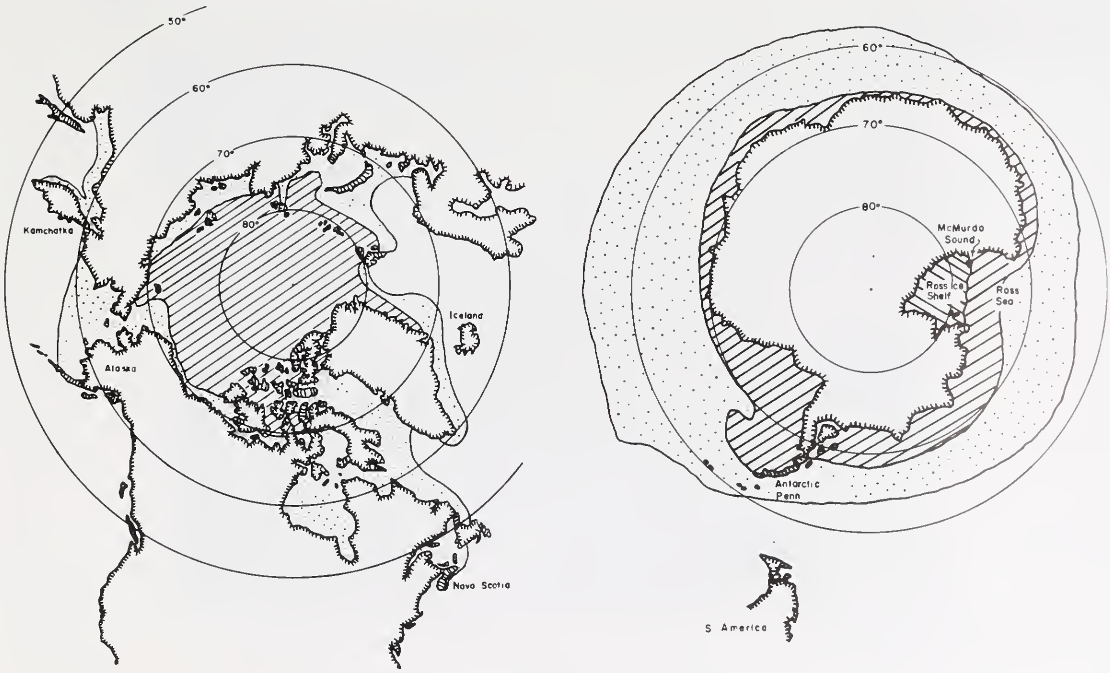

Figure 1. Maps showing approximate range of ice cover in the Northern and Southern hemispheres in summer (shaded) and winter (stippled). (After DeVries, 1974)

quickly freeze and die, thus demonstrating that fishes cannot live in a supercooled state in the presence of ice. There are, however, many polar fishes that inhabit shallow waters where ice is usually present. How is it that these fishes avoid freezing?

The best approach to answering this question might be to examine the physiology and biochemistry of fishes that inhabit environments where the seawater is always at or near its freezing point and where ice is most abundant. McMurdo Sound, Antarctica, is such an environment, having an average water temperature of -1.9°C that varies only a few tenths of a degree with depth and season. The sound is ice covered for 10 to 11 months out of the year, and during the winter the near-shore ocean bottom is covered with a thick mat of ice crystals called anchor ice. Beneath the 2-meter-thick surface ice is the subice platelet layer, which grows to a thickness of 3 meters during the winter. *Trematomus borchgrevinki,* a fish common to McMurdo Sound, is often seen swimming beneath this layer and on occasion has been observed to dart up into it to escape its predator, the Weddell seal. In the mat of anchor ice the naked dragon fish, *Gymnodraco acuticeps,* and the benthic cod, *Trematomus bernacchii,* are frequently seen foraging for food (Figures 2 and 3). Scuba observations have shown that these fishes do not try to avoid the ice but in fact often choose to burrow into icy tunnels in the mat. Although they usually rest on the large ice crystals, with their pelvic and caudal fins making firm contact, they do not appear to freeze. If one nets these fishes and cools them in a refrigerated aquarium to temperatures below the freezing point of seawater in the presence of ice, they quickly go into convulsions, ice crystals appear in their eyes, and they die. If they are plunged into warm water as soon as ice crystals appear in their eyes, they do not recover. Thus any freezing apparently results in irreversible and fatal damage.

If one collects bood plasmas from the McMurdo Sound fishes and determines the freezing points, one finds they all freeze at temperatures below -1.9°C (Figure 4), which is in agreement with the temperatures at which these fishes freeze in the presence of ice. One exception is the plasma of the liparid fish, *Paraliparis deVriesi,* which lives in the deepest part of the sound.

It is instructive to describe exactly how the freezing points discussed here are measured. Freezing and melting points are determined by immersing small capillary tubes (10 microliter capacity) containing the plasmas in a refrigerated bath and observing the temperature at which a small preformed seed crystal begins to increase or decrease in size. The freezing point is defined as the

Figure 2. The naked dragon fish, Gymnodraco acuticeps, *resting on bottom beneath overhanging ice crystals of the anchor-ice mat in 10 meters of water in McMurdo Sound, Antarctica. (A. L. DeVries)*

Figure 3. Trematomus bernacchii *resting on patch of anchor-ice mat, eating on unidentified invertebrate, in 10 meters of water in McMurdo Sound, Antarctica. (A. L. DeVries)*

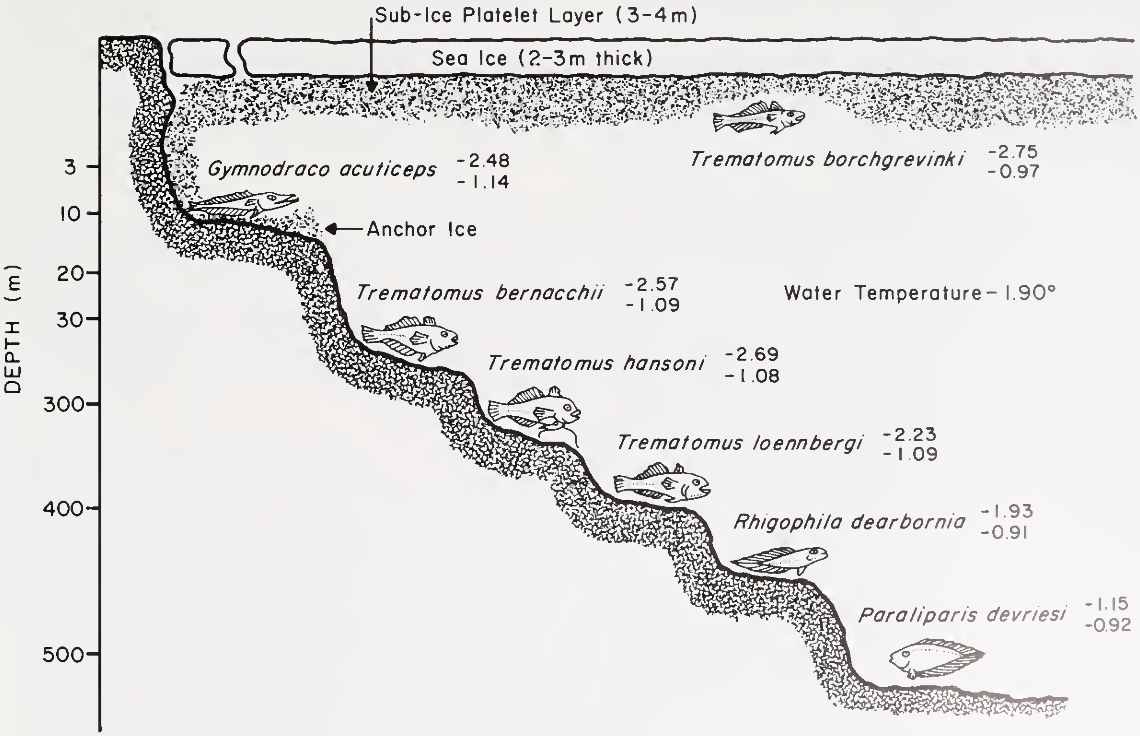

Figure 4. Sketch of McMurdo Sound, Antarctica, showing depths and habitats of the various fishes. The top number is the freezing point and the bottom number is the melting point of the blood plasma.

temperature at which a small seed crystal begins to increase in size as the temperature is lowered very slowly; the melting point is the temperature at which the seed crystal disappears as the temperature is raised. With this technique, freezing and melting of seed crystals can be observed to occur in seawater, in solutions of glucose, and in blood plasmas of tropical fishes within 0.02 to 0.05°C of each other. The average of the freezing and melting temperatures agrees with the freezing points that are given in the literature for these aqueous solutions.

When the plasmas of the McMurdo Sound fishes freeze, a very unusual phenomenon is observed: freezing takes place in the form of long spicules, which look like fine strands of glass wool, that rapidly propagate from the surface of the seed crystal. Another unusual observation associated with the freezing-melting behavior of these plasmas is that melting of the spicular crystals and seed crystal occurs from 1 to 1.5°C above the freezing temperature. In other words, the freezing points and melting points differ markedly—a phenomenon that is not observed in the freezing-melting behavior of other colloidal and salt solutions, or with the plasmas of temperate-water fishes.

The same strange freezing behavior has been reported in the wintertime for plasmas of the saffron cod, *Eleginus gracilis*, the sculpin, *Myoxocephalus verrucosus*, and the winter flounder, *Pseudopleuronectes americanus*, which inhabit the Bering Sea and the coastal waters of Nova Scotia. The freezing points of these plasmas are below the freezing point of seawater only during the winter; they rise as the summer temperatures increase. In the Antarctic, where the water is always at its freezing point, fishes maintain plasma freezing points below -1.9°C during both the winter and the summer (Table 1).

It is clear that the blood of the antarctic and northern wintertime fishes differs in its freezing behavior from that of fishes from warmer climes. What are the solutes that are responsible for these low freezing points and, in particular, how do they prevent these cold-water fishes from freezing?

In the blood of temperate fishes, sodium chloride ($NaCl$) accounts for 85-90 percent of the blood freezing point depression. The remainder is due to the presence of small molecules such as potassium, glucose, urea, and the free amino acids. In polar fishes the concentration of $NaCl$ is only 20-30 percent higher than in tropical and temperate fishes, and the other plasma solutes are even less elevated. In the case of *T. borchgrevinki*, these salts account for only 45 percent of the observed freezing point depression. The remainder has been shown to be due to a series of glycoproteins. The same is true of the saffron cod. In the sculpin and winter flounder, however, the principal agents of depression are small proteins called peptides. For simplicity, these organic molecules are referred to as "antifreezes." Their contribution to the freezing point depression of the plasmas can most easily be shown by partitioning the plasmas into large and small components and measuring the freezing points of each. This is most readily done by putting the

Table 1. Freezing and melting points of the blood plasmas of antarctic, arctic, and north-temperate fishes during the winter and the summer.

Species	Environmental Temperature (°C)		Freezing Point (°C)	Melting Point (°C)
Antarctic (McMurdo Sound)				
Trematomus borchgrevinki	-1.9	winter	-2.75	-0.97
("antarctic cod")	-1.7	summer	-2.63	-0.90
Arctic (Bering Sea)				
Eleginus gracilis	-1.7	winter	-2.1	-1.1
(saffron cod)	+7	summer	-0.68	-0.61
North-temperate (Nova Scotia)				
Pseudopleuronectes americanus	-1.2	winter	-1.47	-0.71
(winter flounder)	+16	summer	-0.58	-0.58

plasma into a dialysis sac and immersing it in a large volume of distilled water (Figure 5). After several hours the salts will have diffused out of the plasma into the large volume of water. After dialysis, half of the freezing point depression is associated with the colloidal particles inside the sac, as well as the large freezing-melting point difference. For example, after 24 hours of dialysis, *T. borchgrevinki* plasma freezes at -1.5°C and melts at -0.02°C. The freezing and melting points of dialyzed plasma of a temperate fish are both approximately -0.02°C. Such dialysis experiments show that the antifreeze components of the plasma are colloidal particles.

Eight glycoprotein antifreezes have been isolated from the dialyzed blood plasma of the antarctic fishes and have been more thoroughly characterized than those isolated from the northern fishes. These glycoproteins are simple compounds composed of only two amino acids—alanine and threonine—and two sugar residues—galactose and N-acetyl-galactosamine. The glycoproteins occur in eight sizes. They are long, narrow molecules, unlike most other proteins and glycoproteins, which are globular. They possess many hydroxyl groups, which make the molecules very soluble in water and also allow them to interact with ice (Figure 6).

The antifreezes isolated from the northern fishes are presently being characterized in our

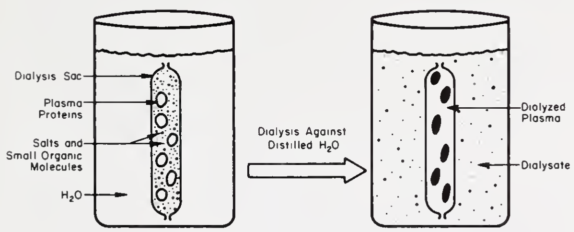

Figure 5. The salts and small organic molecules present in the plasma of polar fishes can be separated from the colloidal particles (proteins and glycoproteins) by dialysis. After 24 hours of dialysis against a large volume of distilled water, the dialysis sac contains primarily plasma proteins, which in most fishes have little effect on the freezing point of the plasma. In polar fishes that possess antifreezes, half of the freezing point depression of the plasma is associated with the colloidal particles inside the sac. The water surrounding the sac is called the dialysate, and after dialysis it contains most of the salts and small organic molecules. When the dialysate is concentrated to the original volume, its freezing and melting points are the same and approximate the melting point of the native plasma.

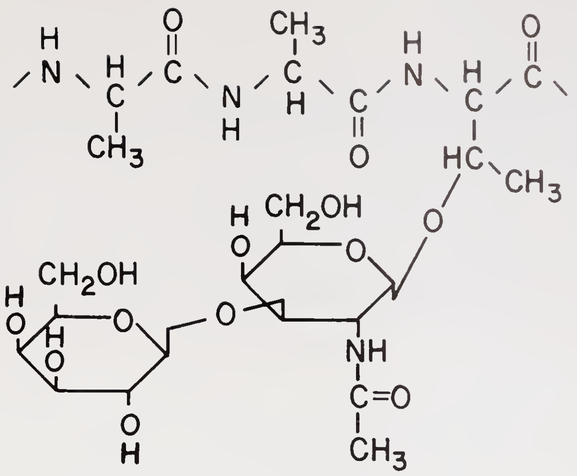

Figure 6. Basic repeating unit of glycoproteins with antifreeze properties. The antifreeze molecule is composed of a polypeptide backbone of two amino acids, alanine and threonine, in the sequence of alanine-alanine-threonine, with the disaccharide β-D-galactose-φ-D-N-acetylgalactosamine linked to every threonine residue.

laboratory. Those from the saffron cod show considerable similarity in basic structure to the glycoproteins isolated from the antarctic fishes, though their antifreeze activity is somewhat less.

The antifreezes isolated from the Bering Sea sculpin and winter flounder differ considerably from the glycoprotein antifreezes (Table 2). They have no sugar components and are composed only of amino acids. Although both of these antifreezes are peptides and on a weight basis produce the same freezing point depression as the large glycoprotein antifreezes from the antarctic fishes, they differ substantially in composition. The peptides from the sculpin have thirteen different kinds of amino acids, while the ones from the winter flounder have only seven different kinds. Despite this gross difference they have certain similarities, the most striking one of which is their large alanine and polar amino acid residue content. This similarity might prove to be important in their activity on freezing point depression.

Distribution of Antifreezes in the Body Fluids

One of the first questions that come to mind after discovering that these fishes have so many different-sized antifreeze molecules composed of the same sugar and amino acid building blocks is why a single molecular species cannot provide adequate

Table 2. Comparison of types and molecular weights of antifreezes isolated from the plasmas of antarctic, arctic, and north-temperate fishes.

Species	Type of Antifreeze	Molecular Weights
Antarctic		
Trematomus borchgrevinki ("antarctic cod")	Glycoprotein	2,600 to 33,700
Arctic		
Eleginus gracilis (saffron cod)	Glycoprotein	5,000
Myoxocephalus verrucosus (sculpin)	Peptide	5,000
North-temperate		
Pseudopleuronectes americanus (winter flounder)	Peptide	3,000 to 5,000

protection. At this time too little is known about the various antifreezes, especially in the northern fishes, to give a sound answer to this question. Only in the antarctic fishes have detailed studies been done, and there the picture is not entirely clear as to what the function of each size is.

All eight glycoprotein antifreezes have been isolated from the blood plasmas of the antarctic fishes, and on a weight basis they are present at concentrations of 4 percent (weight/volume). In these fishes the eight sizes are also found in the fluids of the body cavity, heart, and eye. Only the small ones have been found inside the cells of the liver and muscle. It therefore appears that the small glycoproteins may play a role in preventing the cells from freezing, while all eight sizes function to protect the extracellular fluids from freezing. At this time one can only speculate that the small antifreezes found in the other fishes play similar roles.

None of the antifreezes have been found in the urine of the antarctic or northern fishes. In the case of the antarctic species this is not highly unusual, because these fishes have aglomerular kidneys. In animals with such kidneys, the blood is purified by secretion of wastes and toxic substances from the blood into the kidney tubules to form urine. Each waste substance is handled by a specific process, and all others, including the antifreezes, are retained in the blood. The kidneys of most fishes, however, are glomerular. In this case all small molecules are filtered into the urine, and useful substances are then resorbed from the urine. The glycoprotein and peptide antifreezes, being small, ought to be filtered into the urine of the northern polar fishes, but they are not. Why they are not is unclear, although it is suspected that these fish have reduced or altogether stopped filtration at the glomerulus. In other words, they are functionally aglomerular. In terms of energetics it would be inefficient for the polar fishes to loose their antifreezes via the urine. Thus it appears that adaptation to freezing environments not only has taken the form of a system for synthesis of unique antifreeze molecules, but also has involved the modification of kidneys to prevent the loss of these molecules once they are synthesized.

How Antifreezes Work

The freezing and melting behaviors of the glycoproteins and peptide antifreezes have been studied in detail. All of the antifreezes affect the freezing and melting points of water the same way, although to differing degrees. Their most remarkable property lies in the way they lower the freezing temperature of water. The depression of the freezing point of a solution depends on the number of solute particles dissolved in the solution

and not on the size of the particles. For example, a mole of NaCl, which produces two moles of ions (Na^+ and Cl^-) when added to a kilogram of water, will depress the freezing point of water twice as much (3.72°C) as will a mole of glucose (1.86°C), even though the molecules of the latter are several times larger than the sodium and chloride ions. The fish antifreezes do not work in this fashion. They produce the same lowering of the freezing point of water as does an equal weight of NaCl, although they are 100 to 200 times larger and are therefore present as fewer particles in solution.

As previously noted, solutions containing the peptide and glycoprotein antifreezes melt and freeze at widely separated temperatures, a fact that would seem to imply that the antifreezes simply slow the rate at which the seed ice crystal grows. Recent experiments, however, have clearly demonstrated that no detectable growth occurs at the surface of a seed crystal even after a week at a temperature between the freezing and melting point of a 1 percent solution of antifreeze. Thus it appears that the antifreezes can effectively prevent ice from propagating in water and also in the body fluids of the cold-water fishes.

The spicular type of freezing typical of antifreeze solutions can be characterized as being rapid and complete at a distinct temperature, as compared to solutions of salt or other proteins. When these solutions are slowly frozen, the solutes tend to be excluded from the ice and concentrated in the liquid phase. The outcome is that as freezing proceeds, the concentration of the solute in the liquid results in a progressively lowered freezing point. Because of this, crystal growth tends to be slow and generally in the form of short, thick spears and plates. The antifreeze molecules, however, do not concentrate in the liquid phase during freezing. One possible explanation for this is that antifreeze molecules bind to the surface of ice crystals, becoming incorporated into the expanding ice front, and interfere with the laying down of water molecules into the ice lattice.

There is some evidence that the glycoprotein antifreeze molecules are long chains of amino acids coiled into an open helix with three amino acids per turn. One amino acid in three has a sugar attached to it, and the sugar groups are thus arranged in a line down one side of the chain. Like all sugars, they have a strong affinity for water. The other amino acids in the chains—those without bound sugar molecules—are nonpolar; that is, they have little affinity for water. In the peptide antifreezes there are no sugar molecules but rather a series of amino acids that have polar groups on them and thus are attractive to water; these may serve the same purpose as the sugars in the glycoproteins. In sum, we have a linear molecule of which one side is wettable and will bind to the ice crystal, and the other is water repellent and will discourage crystal growth (Figure 7).

Evolution of Antifreezes

The fact that the cold-water fishes have evolved a means of protection against freezing that does not employ high concentrations of ions and small organic molecules deserves special mention here. The evolution of the process appears to have occurred in the simplest way possible, one in which the amounts and kinds of salts present in the body fluids have not been significantly altered.

Fishes of the Antarctic Ocean were not always faced with freezing conditions. Fossils associated with the *Glossopteris* flora have recently been unearthed in the interior of the antarctic polar plateau and indicate that the climate was once much warmer. As the climate of the Antarctic became colder, the temperature of the surrounding ocean was cooled to its freezing point and became covered with ice. In order for fishes to remain in these freezing waters, a mechanism for prevention of freezing had to evolve. At first glance it would appear that perhaps the easiest such adaptive change would have been concentration of body fluids to the point where the fishes had the same amount of salt as does seawater. This would have required some changes in their physiology. Sodium, potassium, and chloride, the most common ions in seawater, are also intimately involved in the conduction of nervous impulses, and thus fishes expend considerable energy in maintaining concentrations well below those found in seawater. In order for the nervous system to function in the presence of increased concentrations of these ions, significant changes in the architecture of the nervous system would have had to occur. These changes would have most likely involved restructuring of the nerve membranes, which are composed of many complex proteins and lipids.

Lowered freezing points could have also been attained by increasing concentrations of small organic molecules in the body fluids. Changes in

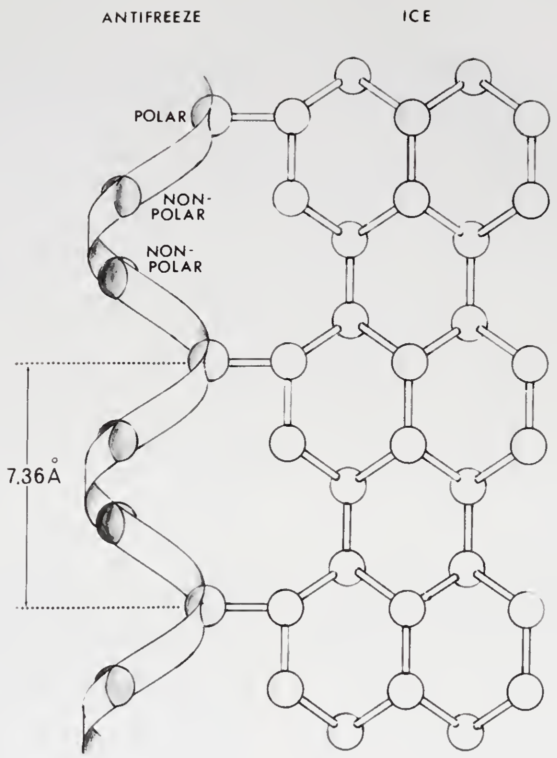

Figure 7. A model showing how the glycoprotein and peptide antifreezes could bind to the surface of an ice crystal if their structure is a helix with three amino acids per turn. Every third amino acid has a sugar attached or has a polar side-chain that is capable of bonding with the oxygen or hydrogen atoms of the water in the ice crystal. If the repeat distance of the amino acids in this helix is similar to that of the water molecules in the crystal (in this case the C axis of the crystal, which has a repeat distance of 7.36Å), the resulting match would enchance the bonding of the glycoprotein or peptide antifreezes to the ice crystal.

these solute concentrations, however, would have undoubtedly led to complications, because most of the small organic molecules are either substrates or products of the many biochemical reactions that provide energy for maintenance, growth, and reproduction in fishes.

It appears then that from an evolutionary point of view, the most conservative pathway to freezing avoidance involved synthesis of relatively few molecules of glycoprotein or peptide antifreeze that were extremely efficient in lowering the freezing point. Accumulation of ions or small organic molecules would have necessitated the restructuring of many enzymes and structural proteins of the metabolic and nervous system, which would have been an extremely complicated process.

Evolution of the various glycoprotein and peptide antifreezes appears to have occurred independently in unrelated families that are separated by geographical barriers. The saffron cod in the Bering Sea and the antarctic cod in McMurdo Sound, although not closely related, both evolved very similar glycoprotein antifreezes. The sculpin, which also inhabits the same waters of the Bering Sea and is more closely related to the saffron cod than the antarctic fishes, employs a peptide antifreeze. The exact mechanism by which these quite different antifreezes give rise to the same effect is still unresolved and is a subject of great interest.

Research Implications

The discovery of the glycoprotein and peptide antifreezes provides an explanation for the low freezing points of cold-water fishes and also as to the nature of the protective compounds. How

these simple molecules interact with water or ice to prevent liquid water, at temperatures where it should be solid, from turning to ice poses a provocative question to biophysicists and physical chemists. There is a possibility that the molecules achieve their effect by modifying the structure of water, but there are no good techniques for determining alteration of water structure. It is more likely that future efforts will be directed towards understanding the processes involved in crystallization, because small amounts of impurities are known to be able to inhibit the crystallization of salts from supersaturated solutions. The impurities bind to the crystal nuclei, preventing them from growing, or causing them to grow in unusual forms. There is evidence that the antifreezes bind to ice, and when ice does grow, its crystal form is very unusual. Perhaps the antifreezes could be viewed as impurities that bind to ice nuclei and produce inhibition of crystallization similar to that observed with salt solutions.

The glycoprotein antifreezes may also be of importance to the field of carbohydrate chemistry. Because of their structural simplicity they become excellent model systems for those persons who are interested in studying more complex glycoproteins. They can be used to elucidate the utility of several of the common chemical procedures and enzymatic techniques that are employed in structural determination of complex glycoproteins such as human blood group substances and serum glycoproteins. When used for determining complex glycoprotein structure, these chemical and enzymatic procedures have many problems associated with them. Thus studies of the antifreeze glycoprotein as a model glycoprotein could provide valuable information about the limitations of these reactions.

There is also the possibility that the glycoprotein compounds may turn out to be useful cryoprotective agents. The lifetime of many organic materials such as prostaglandins (the new "miracle drugs"), human and domestic livestock sperm, blood, and whole organs can be greatly extended at low temperatures. Generally, the lower the temperature, the longer is the storage lifetime, provided that freezing does not occur. The ability of the antifreeze molecules to retard the growth of ice and to prevent the build-up of high salt concentrations during freezing makes these molecules promising candidates for cryopreservatives. So far, however, it has not been demonstrated that the antifreezes have a cryoprotective effect when red blood cells are frozen in their presence. Even if they do not prove to be cryoprotective agents, they will still be of value in studying the effects of freezing because of their ability to alter the way in which ice grows and to prevent the concentration of salts during freezing.

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Uses and Cultivation of Seaweeds

by Richard A. Fralick and John H. Ryther

There are four major groups of seaweeds, or macroscopic marine algae, that inhabit the shallow coastal waters of the world. The brown algae (Phaeophyta) primarily occupy the intertidal or upper subtidal zones of rocky shores. Larger members of this group such as *Laminaria* and *Macrocystis*—collectively known as kelp—grow rapidly in the cooler, subtidal waters of the northern Atlantic and Pacific oceans. Both plants are sources of a colloid known as algin, which is widely used as a stabilizer in the food and drug industries.

Intertidal and subtidal zones on the east and west coasts of the United States also support representatives of the red algae (Rhodophyta) such as *Chondrus, Gigartina,* and *Gracilaria,* which, though slow growing, occur in substantial quantities. Their chemical products, or colloids, are carrageenan and agar, which are also used as thickeners and stabilizers in the food industry. *Porphyra,* a membranous red alga, is ubiquitous but occurs in abundance off the coasts of China and Japan, where it thrives in nutrient-rich inshore waters. *Porphyra* is used directly as a food source and requires no chemical extraction.

The green algae (Chlorophyta) such as *Ulva, Codium,* and *Enteromorpha,* though of lesser importance, are also used in the Far East as a direct food source. This group is characterized by rapid growth in intertidal and shallow waters, where there are high nutrient concentrations and abundant sunlight.

Cultivation of Porphyra *(nori) in the Inland Sea of Japan. (After Bardach et al., 1972)*

The fourth group of seaweeds consists of the blue-green algae (Cyanophyta), usually relatively small plants having no commercial significance as far as food source or colloidal content is concerned.

Indeed, the red and brown algae are the most valued of the seaweeds. In addition to their scattered use as cattle fodder, fertilizer, and mulch, they are utilized in the Western World primarily for their colloids (Table 1), which are found in a wide variety of foods, drugs, cosmetics, and other products.

Harvesting Techniques

Methods of collecting seaweeds throughout the world are basically primitive and unsophisticated. In Japan, for example, *Porphyra* spores are released in large tanks of seawater into which mesh nets are rolled and dipped. The nets are then attached to poles in nutrient-rich coastal waters, where the plants grow to maturity and are harvested by hand picking. In New England and in the Canadian Maritimes, *Chondrus* and *Gigartina* are harvested by hand with special rakes or by rakelike dredges that scour the algal beds. Occasionally, northeast storms wash large quantities of *Chondrus* ashore, where it is harvested by hand. On the west coast of the United States, Kelco Company, a major processor of algin, uses a mowing vessel to harvest the upper few feet of *Macrocystis* fronds (Figure 1).

Monetary Values

In 1971 Robert Wildman of the Office of Sea Grant estimated the following values for annual worldwide production of seaweed derivatives.

—Agar, from *Gelidium* and *Gracilaria:* 9800 metric tons, valued at $46 million.

—Carrageenan, from *Chondrus* and *Gigartina:* 8640 metric tons, worth $34 million.

—Algin, from *Macrocystis:* 3900 metric tons, at a value of $35 million.

The values of seaweeds have certainly increased along with a developing colloid industry. Current market figures, however, are not available.

Table 1. Commercially important North American seaweeds (after Neish, 1976).

Genus	Common Trade Names	Uses	Region
*Chondrus**	Irish moss	Carrageenan source	Atlantic
*Gigartina**		Carrageenan source	Atlantic/Pacific
Iridaea		Carrageenan source	Pacific
*Ascophyllum**	Rockweed	Alginate source, fertilizer, food, condiment	Atlantic
*Laminaria**	Kelp, kombu	Alginate source, fertilizer, food, condiment	Atlantic
*Nereocystis**	Pacific kelp	Alginate source, fertilizer, food, condiment	Pacific
Macrocystis	Pacific kelp	Alginate source, fertilizer, food, condiment	Pacific
Ahnfeltia		Agar source	Atlantic
Gracilaria		Agar source	Atlantic/Pacific
Phyllophora		Agar source	Atlantic/Pacific
*Furcellaria**		Danagar (Furcellarin) source	Atlantic
Alaria	Wakame†	Food, condiment	Atlantic/Pacific
*Rhodymenia**	Dulse	Food, condiment	Atlantic/Pacific
Porphyra	Nori, laver	Food, condiment	Atlantic/Pacific
Monostroma	Sea lettuce	Food, condiment	Atlantic/Pacific
Ulva	Sea lettuce	Food, condiment	Atlantic/Pacific

*Presently utilized commercially in Canada. †Usually refers to *Undaria* but is also used for *Alaria.*

Methods of Cultivation

New uses for seaweed colloids are being discovered almost faster than the plants can be harvested from their natural habitats. In fact, the possibility of overharvesting naturally occurring seaweed resources has placed increasing pressure on the scientific community to develop economical methods of growing seaweeds much like a terrestrial crop.

The cultivation of seaweeds has been practiced for over 3000 years in the Orient, where several species of marine algae are used directly as food—among others, *Porphyra* (nori or laver), *Undaria* (wakami), *Enteromorpha* or *Monostroma* (aonori) in Japan, and *Laminaria* (kelp) in China. Cultivation consists of growing the large, sporophytic plant from microscopic spores that are "seeded" onto twine nets on wooden frames, or onto ropes suspended from bamboo poles, or otherwise attached to other substrates in estuaries or sheltered coastal embayments (Figure 2). The seaweeds must be continually "weeded" by hand to remove epiphytes, and the Chinese sometimes fertilize the surrounding water by spraying nutrients or allowing them to seep from porous earthen jugs suspended on the culture ropes (Figure 3). A great deal of care and sophistication is also involved in the spore-production phase of the operation, which is usually done in laboratories or "hatcheries" under controlled conditions.

A rather primitive form of seaweed farming for *Eucheuma* has been developed in the Philippines by M. S. Doty (1973) and H. S. Parker (1974) using a net-culture technique that is similar in many respects to seaweed cultivation in Japan. Although labor intensive, the system appears very promising, with dry-weight yields from pilot farm operations reported at 13 metric tons per hectare per year and projected yields of 30 metric tons per hectare per year.

The giant kelp, *Macrocystis pyrifera,* is one of the most important resources of the California Coast, not only as the world's major source of algin, but also as the dominant species and habitat of the local ecosystem. Deterioration of the kelp beds over the past several decades from pollution, predation, or both, has been a matter of major concern. This led W. J. North (1974) and his associates at the California Institute of Technology to attempt rehabilitation of the kelp beds by cultivation techniques, basically the mass rearing of sporlings that are then "seeded" in the environment to be repopulated. Recently Jackson and North (1973) initiated a more ambitious kelp-farming operation that is scheduled to include an artificial upwelling system to provide the plants with cold, nutrient-rich waters and that has as a major objective the production of organic matter as an energy (methane) source.

Figure 1. The kelp cutter Kelsol *harvests* Macrocystis *in the beds off San Diego. (Courtesy of Kelco, Division of Merck & Co., Inc., San Diego)*

At about the time that North's kelp cultivation project got underway, a group at the Canadian National Research Council's Atlantic Regional Laboratory, Halifax, Nova Scotia, under A. C. Neish (1971), initiated research on the culturing of *Chondrus crispus.* Here the approach was to grow the seaweeds unattached in tanks of flowing seawater in a greenhouse. Neish was highly successful with this method and, among other achievements, isolated a strain of *Chondrus* (T-4) characterized by rapid growth and high carrageenan content.

Following Neish's lead, two commercial seaweed companies—Marine Colloids, Inc., of Rockland, Maine (and its Canadian subsidiary), and Genu Products Canada Ltd. (a subsidiary of a Danish firm now owned by Hercules Corporation, Wilmington, Delaware)—started pilot *Chondrus* culture projects in Nova Scotia, with partial support from the Canadian government, each using a different modification of Neish's basic technique. One of the major objectives of the Marine Colloids

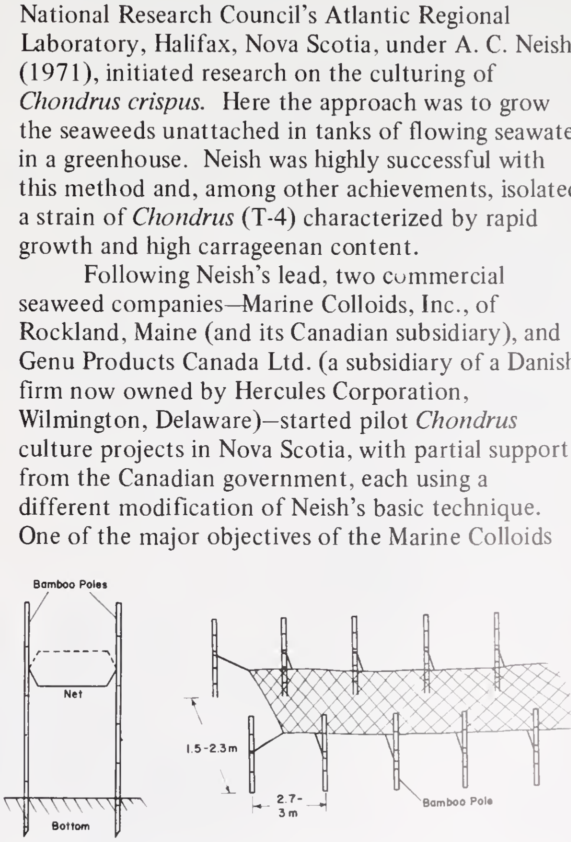


Figure 2. Racks of bamboo poles and nets used in growing Porphyra *in Japan. (After Bardach et al., 1972)*

Uses of Seaweeds throughout the World

Porphyra (nori)—in soups, sauces, salads, and sandwiches; as small squares to pick up rice; as a condiment.

Rhodymenia palmata (dulse)—eaten dried or raw and as a flavoring in soups and salads; reportedly used as a laxative.

Ulva, Monostroma, and *Enteromorpha* (aonori)—sources of salt, mixed with other vegetables in salads and cooked dishes.

Gelidium, Gracilaria, and *Furcellaria*—sources of agar for bacterial cultivation in hospital and university laboratories; in cosmetics and hand lotions; as substitutes for gelatin; in shoe polish and photographic manufacturing.

Laminaria (kelps) and *Undaria* (wakame)—in soups, sauces, salads, teas, garnishes, and vegetable dishes; coated, as candy; as a source of Vitamin C (kelp pills).

Ascophyllum and *Fucus* (rockweed)—poultry meal, fertilizer, and garden mulch.

Chondrus, Gigartina, Eucheuma, and *Neoagardhiella* (carrageenan)—in blancmange and jellies; as a meat and fish preservative; as an emulsifier; to keep pigment and abrasives in suspension in paints and dental products; even in preparation of laxatives, cosmetics and skin creams; in ice cream, whipped cream, etc.

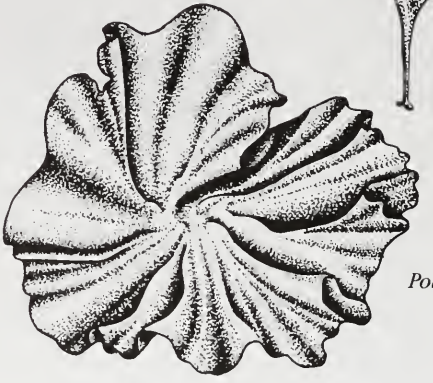
Macrocytis and *Nereocystis* (giant kelp)—to stabilize ice cream; as a general thickening agent; as an important source of sodium alginate.

Enteromorpha, Codium, and *Ulva*—potential energy sources.

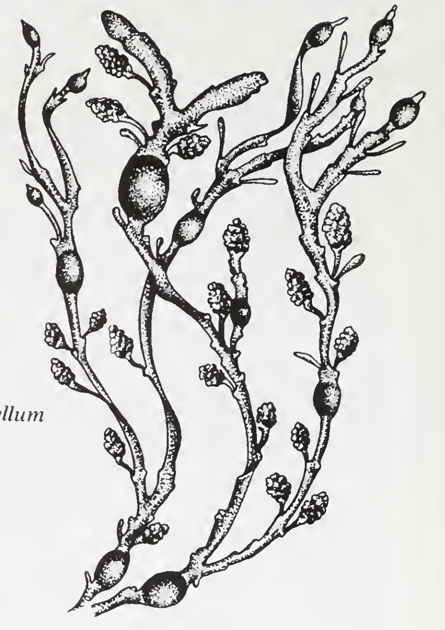
Marine algae are also widely utilized as cattle, hog, and poultry fodder. Historically, the Chinese and the Japanese used seaweeds to treat goiter and various glandular disorders; the Romans, to heal burns, wounds, scurvy, and rashes.

Text adapted from Chapman, 1950, and Mathieson, 1975. Drawings by Nancy Barnes after Chapman, 1950 (*Macrocystis*), Mathieson, 1975 (*Gracilaria*), and Ihsan Al-Shehbaz (all others).

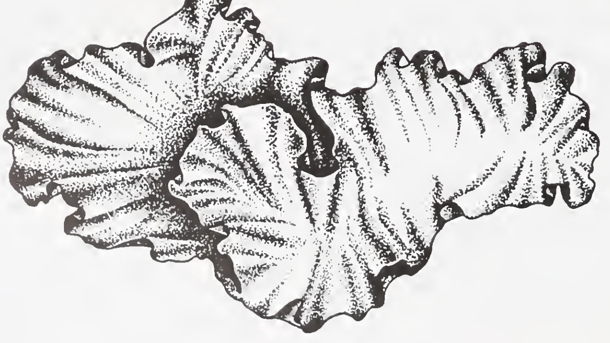
Chondrus
½X



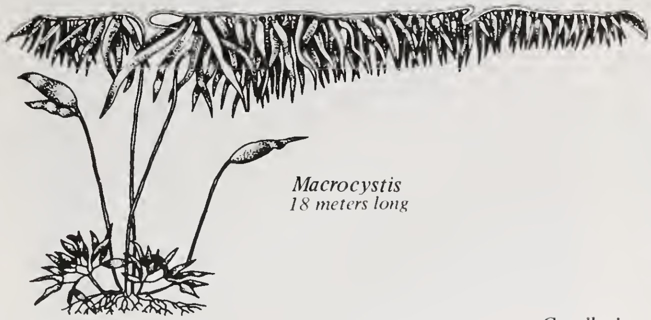
Porphyra
½X



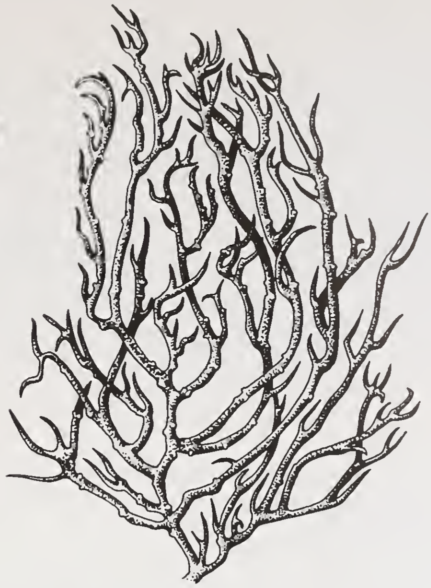
Ascophyllum
½X



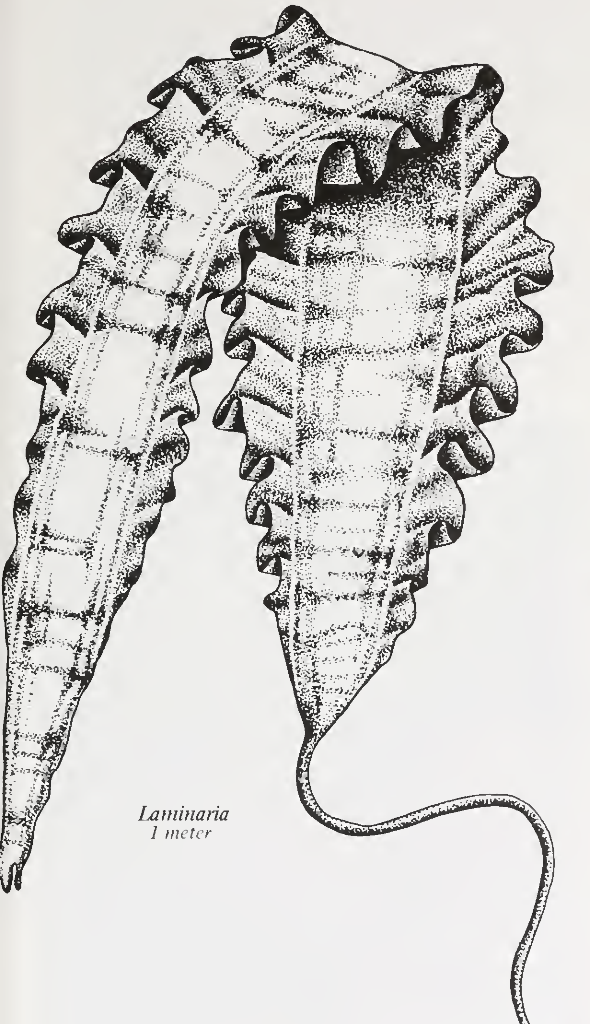
Ulva
½X



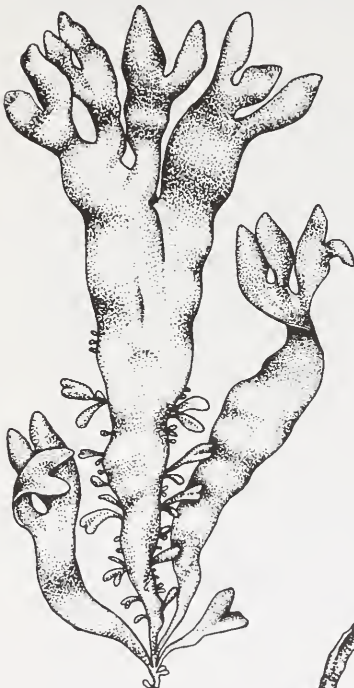
Macrocystis
18 meters long



Gracilaria
½X



Laminaria
1 meter



Rhodymenia
½X

Enteromorpha
½X

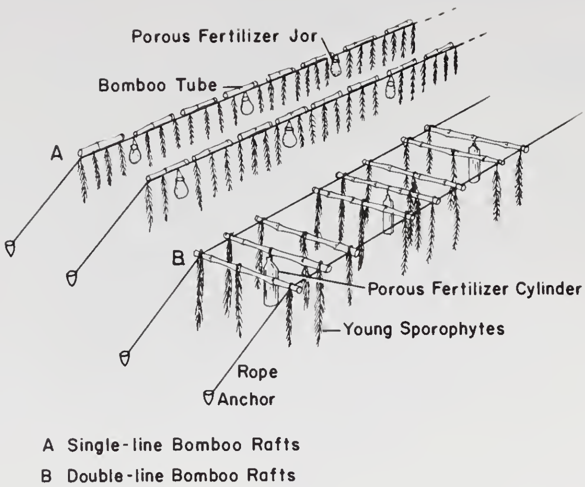


Figure 3. Rafts of bamboo tubes and string for kelp culture in China. Nutrients seep from porous jars or cylinders and fertilize the surrounding waters. (After Cheng, 1969)

project is to screen samples collected from a large number of natural *Chondrus* beds in an attempt to select improved strains with respect to growth, carrageenan content, and other favorable characteristics. Problems encountered by both projects include control of epiphytic algae (for example, *Ulva, Enteromorpha, Ectocarpus)* in the culture system, and slow growth of the *Chondrus.*

During this decade a number of phycologists have conducted relatively small-scale experiments on the photosynthesis, growth, hydrocolloid content, and other characteristics of *Chondrus crispus* and other commercially valuable red algae (for example, Mathieson and Burns, 1971). Many of these studies were partly funded by the seaweed industry, with the objective of developing techniques for the cultivation of carrageenan-containing species other than *Chondrus.* As an outgrowth of that research, Marine Colloids now has a modest pilot experiment in the Florida Keys looking at the potential cultivation of *Eucheuma* spp., *Hypnea musciformis,* and other tropical and semitropical red algae, and plans a similar effort in the culturing of *Iridaea* and *Gigartina* (Waaland, 1973), which are temperate Pacific species, in the Washington State area.

In 1970 a project was started at the Woods Hole Oceanographic Institution to develop a waste recycling-marine aquaculture system (Ryther, 1976). Secondary sewage effluent, mixed with seawater, is used to grow unicellular algae (phytoplankton) that are later fed to oysters, clams, and other bivalve molluscs. The algae remove the nutrients (primarily nitrogen) from the waste water, and the shellfish remove the algae, the combined system providing a tertiary sewage treatment (nutrient removal) as well as a crop of commercially valuable seafood. However, metabolism of the bivalves and other animals in the aquaculture system results in remineralization of a portion of the nutrients contained in their food; nitrogen and phosphorous are therefore returned to the water through the animals' excretion and the decomposition of their solid wastes. This phenomenon necessitated the addition of a final step to remove the regenerated nutrients, that is, seaweeds grown in suspended culture (Figure 4).

Initially *Chondrus crispus* was used in this project, including the T-4 strain obtained from Halifax, but the *Chondrus* grew slowly and became heavily overgrown with epiphytic seaweeds. It was subsequently replaced by other warm-water species that appear as summer annuals in the Woods Hole region, including *Neoagardhiella baileyi, Gracilaria foliifera,* and *Hypnea musciformis.* So successful has been the growth of these algae, especially that of *Neoagardhiella* and *Gracilaria,* that a separate project was begun in which the seaweeds alone are grown in mixtures of sewage effluent and seawater as a one-step waste recycling-aquaculture system (Figure 5). Similar experiments were started in 1973 at the Harbor Branch Foundation, Ft. Pierce, Florida, using more tropical species of seaweeds, *Solieria tenera* and *Gracilaria cylindrica.*

Figure 4. Ryther inspects Gracilaria *grown in suspended culture in Woods Hole. (Brian Lapointe)*

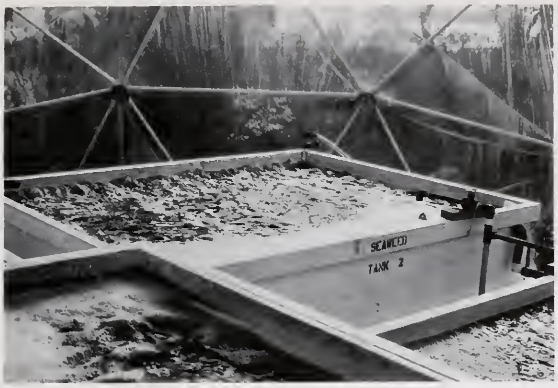


Figure 5. Experimental growth tanks for Gracilaria *and* Neoagardhiella. *The seaweeds are grown unattached in tanks of seawater and sewage effluent as a one-step waste-recycling system. During the winter months the seaweeds are often grown in a greenhouse (in this case a polyethylene-covered geodesic dome) to conserve heat. (Brian Lapointe)*

It is also important to realize that seaweeds can be grown in coastal wetlands or salt water impoundments along the shore on land that is unsuitable for agriculture because of soil, drainage, rainfall, or other reasons. In other words, large-scale seaweed culture could represent a new crop of organic matter on land that is not presently in production or capable of any significant yield of terrestrial vegetation.

Recently Dr. Ernesto Foldats of the Universidad Central in Venezuela, in cooperation with the Venezuelan government's division of science and technology, has discovered rich natural beds of the agarophyte *Gracilaria domingensis.* However, Foldats and other conservation-minded Venezuelan algologists are attempting to develop an inexpensive means of cultivating the *Gracilaria,* using the natural resource only as a seed-stock to initiate cultivation. This approach will prevent overharvesting and presumably will provide long-term employment for coastal inhabitants, while at the same time utilizing unproductive, government-owned coastal lands. At present, Venezuela imports all of its colloids at costs estimated to be in the millions of dollars.

The Importance of Aquaculture

The rapidly developing market for seaweeds and their colloids has raised the possibility of overharvesting naturally occurring species and has challenged scientists to develop aquaculture systems—both to meet world needs and to conserve seaweeds as a resource. Large-scale aquaculture, however, may be expensive compared with harvesting natural populations. And the cost is further increased by spiraling fuel costs. Thus, the limiting factor to successful seaweed cultivation may be energy. To meet this problem, researchers are investigating the use of seaweeds themselves as an energy source, in that marine algae produce synthetic fuels (methane, ethanol) from the anaerobic digestion of their organic matter. Nuisance seaweeds and algal epiphytes such as *Codium, Enteromorpha,* and *Ulva* are among the green algae currently being considered for this purpose. In the long run, seaweeds may help pay for their own cultivation and preservation.

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Seawater and the Formation of Ores

by Susan E. Humphris and Geoffrey Thompson

We may reasonably infer that water, in its passage through the earth to the principal fissures, imbibes, together with the natural salts and acids, the minerals and metallic particles with which the strata are impregnated.

Pryce, 1778

Almost two centuries after this English geologist wrote of the exchange of material between water and the earth's crust, geologists are now beginning to realize the significance of such processes and their bearing on the formation of ore deposits. A major breakthrough in our understanding of processes on earth came with the theories of continental drift and plate tectonics (*Oceanus*, winter 1974), which provided a framework within which many geological and geophysical observations could be combined to give a unified picture of the evolution of the crust. It became clear that many tectonic events occur along the margins of the lithospheric plates. In particular, the observation has been made that many ore deposits are located along the plate boundaries and tend to be associated with volcanic rocks.

The plate boundaries are of two kinds: destructive margins where one plate down-buckles under another and is consumed (subducted); and constructive margins where new material is added to the edges of the plate, such as at the mid-ocean ridges.

In general we recognize three major kinds of ore deposits along the destructive margins:

1. *Porphyry copper deposits* (with associated metals such as gold, silver, and molybdenum). The world's major porphyry copper deposits are located along the plate boundaries and are generally associated with the andesitic volcanism found on the boundaries of the larger continental masses. Some of the best examples of these deposits are found along the west coasts of the Americas, particularly in Peru and Chile.

2. *Lead-zinc-copper-silver ores.* These occur predominantly on the destructive margins where the interaction of oceanic plates has produced island arcs, such as those found along the western margin of the Pacific. They are often classified into two types (Kuroko or Besshi massive sulfides), depending on whether they are associated with basaltic or more acidic volcanism.

3. *Copper sulfides of ophiolites.* These ores occur as massive deposits associated with submarine-erupted basalts and marine sediments. They are thought to be slabs of oceanic crust that have been shoved up (obducted) onto a continental plate. Figure 1 shows a cross-section of one such ophiolite and the location of the metal deposits. Examples of these deposits are known in Newfoundland, Eastern Canada, the northeastern United States, and Europe. One of the better known examples is the Troodos Massif in Cyprus, where copper has been mined since long before the Egyptian and Greek civilizations were at their peak.

The constructive margins of the plates have only recently been recognized as potential ore-forming sites. Metal-rich sediments (predominantly iron and manganese, but with significant associated copper, nickel, cobalt, zinc, and barium) have been noted along the mid-ocean rifts, particularly on the East Pacific Rise of the Nazca Plate. The Red Sea—a site of incipient sea-floor spreading—is the best known and most studied ore deposit associated with a constructive plate margin. Although the geologic setting is somewhat different from present mid-ocean ridges, and there is an abundance of metalliferous black shales and evaporites close by, the heat from the volcanic activity at the constructive plate margin is the driving mechanism for the circulating seawater, as at the present mid-

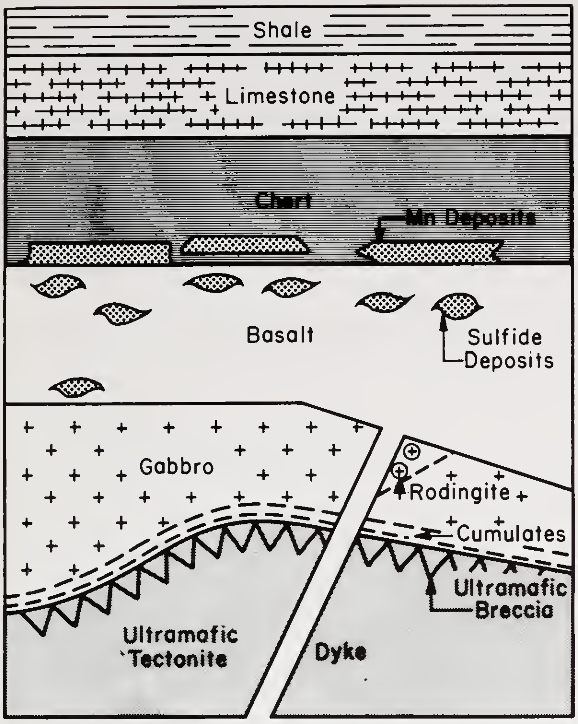

Figure 1. Cross-section of Apennine ophiolite. (After E. Bonatti et al. 1976. Metalliferous deposits from the Apennine ophiolites. Mesozoic equivalents of modern deposits from oceanic spreading centers. Bull. Geol. Soc. Amer. *87:83-94.)*

ocean ridge axes. Here hot brines are found in isolated deeps along the ridge axis. These closed basins have sediments highly enriched in copper, lead, and zinc. The *Atlantis II* Deep (named after the Woods Hole vessel that first surveyed this particular area) is only 50 square miles in area but is thought to contain 3 million tons of zinc, 1 million tons of copper, just less than 1 million tons of lead, and 5000 tons of silver.

In the past few years, metal-rich deposits have also been reported from the Mid-Atlantic Ridge. Iron- and manganese-rich oxides were sampled during the submersible dives in the joint American and French Mid-Atlantic Ridge explorations (Project FAMOUS) of the last two years (*Oceanus,* spring 1975). Iron and copper sulfides have been dredged from the deep equatorial fracture zones. During a recent Woods Hole expedition (cruise 78 of *Atlantis II*) to the ridge, we dredged large (up to 1 kilogram) boulders of pure (99 percent) manganese oxide-todorokite (Figure 2). Similar deposits (although in this case the manganese mineral is birnessite) have also been reported from the ridge a few degrees to the north, at about 25°N.

Ore Formation

Finding and exploiting the ore deposits associated with active plate margins is the major activity of the mining geologist. As oceanographers we are more concerned with understanding the processes by which such metal-rich segregations are formed. In particular, we are interested in those processes at constructive plate margins and the role of seawater in the formation of ores.

The mid-ocean ridges represent the plate boundary along which new oceanic crust is being created by the injection of lava. Geological and geophysical data suggest that seawater circulates through the freshly intruded rocks at the mid-ocean ridge. This process of hydrothermal circulation was originally invoked to explain the pattern of heat flow observed in the oceans. Along the axes of the mid-ocean ridges, much lower heat flow values were measured than those expected for a conductively cooling crust. These values could be explained only by suggesting that seawater circulates through the rock and carries away some of the heat by convection. Thus, molten lava is injected onto the sea floor in a narrow zone at the mid-ocean ridges, and the surface is cooled rapidly by the overlying seawater. This causes cracks and fractures to propagate in the rock, and seawater can then penetrate down these into the hot rock. Reactions between the rock and seawater will continually occur as the water encounters increasing temperature and pressure. Density gradients are established

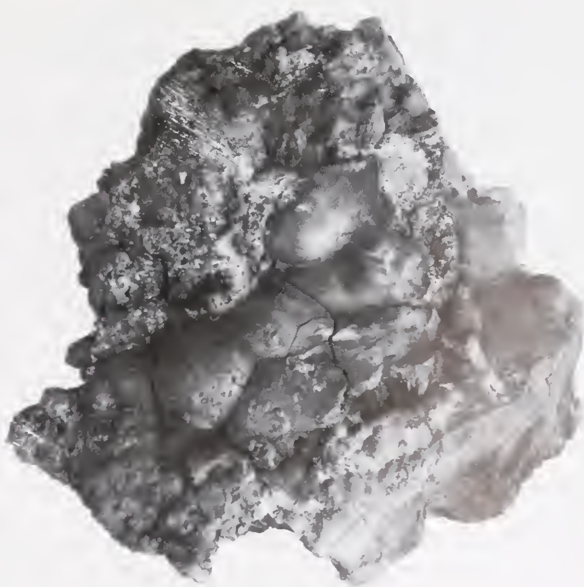

Figure 2. Photograph of manganese ore dredged from the Mid-Atlantic Ridge near 23°N during Atlantis II *cruise 78. (Frank Medeiros)*

as the water is heated, causing the hot fluid to rise and to be debouched onto the sea floor.

Such a circulation gives rise to large-scale chemical fluxes between the oceanic crust and seawater. Since the erupted rock is initially derived from the upper mantle, such interaction between rock and seawater is significant as a path for chemical exchange between the various chemical reservoirs–mantle, crust, and ocean. It is therefore extremely important to try to understand the interaction between volcanic rocks erupted along mid-ocean ridges, and the overlying seawater, since this reaction is fundamental to the cycling of elements through the lithosphere, and is the mechanism for the concentration of metals in the upper crust.

At Woods Hole we have been studying rocks dredged from various regions of the median valley along the Mid-Atlantic Ridge in order to determine the mineralogical and chemical changes that occur during hydrothermal alteration. Metamorphosed basalts, usually belonging to the zeolite, greenschist, or amphibolite facies, have been dredged from the median valleys and the flanks of the ridges, and also from fracture zones. Serpentinites (metamorphosed peridotites) have also been dredged from the fracture zones. All of them are hydrated, but the intensity of alteration is variable. Oxygen isotope data have shown that the fluid involved in this metamorphism is seawater. The isotope values for coexisting minerals in the altered rocks reveal that reactions occurred at temperatures of up to 300°C.

Our studies have shown that the mineralogical changes during hydrothermal alteration are accompanied by considerable chemical exchange between the seawater and volcanic rock. Upon alteration, the fresh pillow basalts, which usually contain crystals of plagioclase feldspar, and sometimes olivine and pyroxene, in a glassy matrix, are altered into greenstones–so called because of their color–in which the major components are generally albite, chlorite, actinolite, and epidote in varying proportions. It has been possible to determine the absolute elemental fluxes by looking at the compositional trends in samples that have a fresh interior and a well-defined altered outer zone.

Of particular interest for the cycling of elements is the observation that the rocks show a twofold increase in their magnesium content. Geochemists presently believe that seawater is maintained at a relatively constant composition because the elemental inputs into the ocean are balanced by their removal into sediments. However, prior to this observation of magnesium uptake by hydrothermal alteration, it was apparent that the removal of magnesium into sediments could account for only about half of the magnesium input. Hydrothermal alteration therefore provides an additional "sink" for magnesium and helps to explain its geochemical balance.

Although some elements, like magnesium, are gained by the rock from seawater, others are leached from the rock. For example, silica, calcium, and iron are carried in solution in the circulating fluid. In addition, the transition metals are leached from the rock, probably as soluble metal chloride complexes.

During circulation beneath the ridges, the hydrothermal fluid continuously changes in composition and encounters varying conditions, such as temperature, pH, and oxidation-reduction (redox) conditions. The resulting reactions with the adjacent rocks thus vary with these controlling parameters. Sulfides are found in many of these altered basalts as veinlets and as disseminated mineralizations. The sulfide can be supplied by the reduction of seawater sulfate in redox reactions involving the oxidation of iron. As the fluid circulates and the physicochemical environment changes, conditions may become favorable for sulfide precipitation. Iron, copper, and zinc partition strongly with the sulfide phases (they precipitate as sulfides rather than remain in solution), and in rocks where sulfide minerals are abundant, the iron and copper contents increase considerably. This process of leaching of transition metals and their reprecipitation at a different location is the probable explanation of the occurrence of the sulfide ore deposits in the ophiolites.

In contrast, manganese is kept in solution during the precipitation of sulfide, and will tend to remain in solution until it comes into contact with the oxygenated seawater. The differing Eh-pH stability ranges of the iron and manganese compounds may explain the variable iron-to-manganese ratios observed in the heavy-metal-enriched sediments at the ridges. Figure 3 shows a simple schematic of the basalt-seawater interaction at mid-ocean ridges.

The 'Geostill' Model

The interaction of seawater and hot rocks with subsequent metal enrichments is but the first stage in a global "geostill" model (Figure 4). We can think of the hydrothermal reactions at the constructive plate margins as being at the beginning of a large conveyor belt in a process designed to distill the metals from the earth's crust and segregate them into exploitable ores.

As the conveyor belt (the oceanic plate) moves away from the ridge, hydrothermal circulation will slow down and eventually stop due to a number of factors. First, the crust will slowly cool and the thermal gradients will diminish, so making the convection cells weaker until they eventually cease to exist. Then, as the crust gets older, the sediment layer will get thicker and may eventually prevent further penetration of large volumes of seawater. Finally, precipitation of secondary minerals along veinlets and cracks will gradually seal off the channels of circulation.

However, even at ambient sea-floor temperatures the volcanic rocks will continue to react with seawater, forming clays and absorbing more water. On the surface of the conveyor belt other metal segregations continue to accrue. These are the so-called manganese nodules. Nodular segregations of iron and manganese oxides with associated nickel, cobalt, and copper grow slowly (less than a centimeter per million years) on the sediment surface. They are apparently formed by precipitation of iron and manganese from the overlying seawater and adsorption of the other metals by these hydrated oxides. In most areas of the sea floor such deposits are diluted by the sediment "raining" down from above, and they do not grow or become significant enough to exploit directly. In some areas, however, such as in the Pacific where the rate of sedimentation is very low, the nodules grow large and abundant. These parts of the conveyor belt may thus be mined directly.

Eventually the crustal plates with their early-formed metal segregations—either by hydrothermal reactions at the ridges or by slow precipitation from seawater—will reach the subduction zones. This is the final part of the earth's "geostill." Some sections of the oceanic plate may be obducted directly onto the other converging plate, giving rise to the ophiolite-type deposits. In general, however, the plate will be down-buckled and be pushed deep down into the hotter regions of the mantle, and further distillation will occur.

The upper part of the downgoing oceanic slab at the trenches will be hydrated owing to the

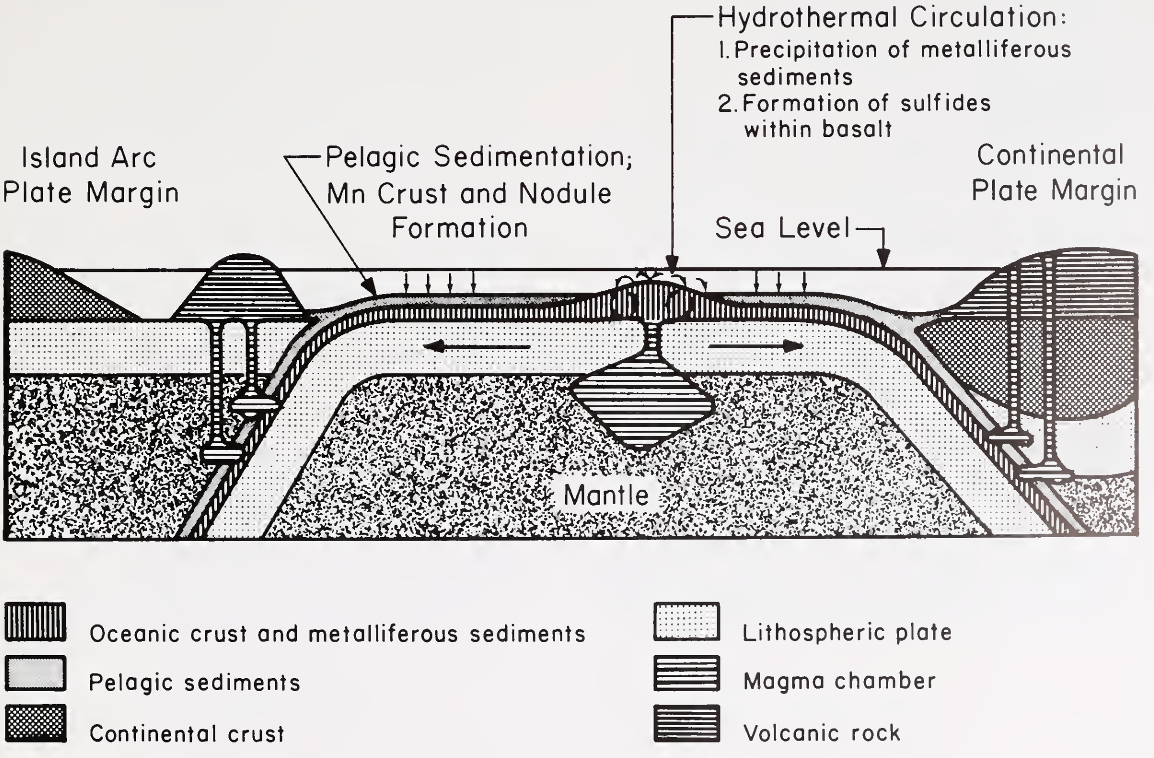

Figure 3. Schematic diagram of hydrothermal circulation at mid-ocean ridges. Seawater penetrates into the hot rock and reactions occur. Magnesium (Mg) and water (H_2O) are gained by the rock; silica (Si), calcium (Ca), iron (Fe), manganese (Mn), and trace metals are released into solution. If the fluid encounters reducing conditions, Fe, copper (Cu), and zinc (Zn) sulfides may precipitate. Finally, the hydrothermal fluid is debouched onto the sea floor, and the trace metals are deposited to form metalliferous sediments. (Drawing by Nancy Barnes)

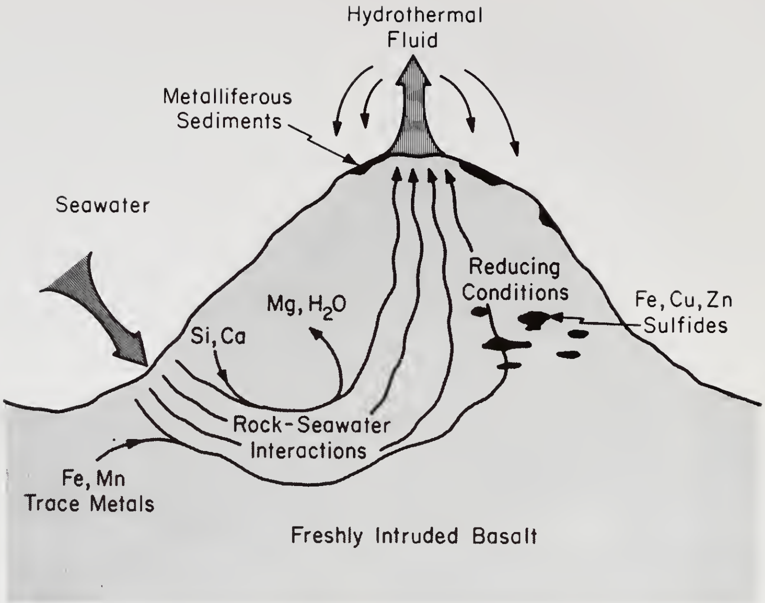

Figure 4. The global "geostill" model, which represents a process to distill the metals from the earth's crust and segregate them into exploitable ores. (Drawing by Nancy Barnes. Adapted from A. L. Hammond. 1975. Minerals and plate tectonics: a conceptual revolution. Science *189: 779-81. Copyright 1975 by the American Association for the Advancement of Science.)*

uptake of water during both low- and high-temperature alteration of the oceanic basement rocks. As the water lowers the melting point of the rock, the hydrated part will be the first to melt. This will produce the volcanism observed in the plate margins. However, crust that melts first may well contain some sulfides that have previously been concentrated by hydrothermal processes at the mid-ocean ridge. This further distillation, and the possibility of leaching additional metals from the overlying plate, can result in highly enriched metal segregations. Subsequent migration, in association with volcanism, results in the economically exploitable sulfide and porphyry copper deposits often observed on the landward side of converging plate margins.

This idea is purely speculative, and any such hypothesis may be difficult to prove because the convergent plate margin is an extremely complex structure. However, much attention is now being focused on a reassessment of ore formation processes in the context of plate tectonics, and perhaps seawater will turn out to be the missing link between hot rocks and ore deposits.

Susan E. Humphris is a graduate student in chemistry in the WHOI-MIT Joint Program. Geoffrey Thompson is an associate scientist in the Department of Chemistry, Woods Hole Oceanographic Institution.

Suggested Readings

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Hammond, A. L. 1975. Minerals and plate tectonics: a conceptual revolution. *Science* 189:799-81.

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AIR-SEA INTERACTION, Spring 1974–Air and sea work with and against each other, mixing the upper ocean, setting currents in motion, building the world's weather, influencing our lives in the surge of a storm or a sudden change in patterns of circulation. Seven authors explain research in wave generation, hurricanes, sea ice, mixing of surface waters, upwelling, long-range weather prediction, and the effect of wind on circulation.

ENERGY AND THE SEA, Summer 1974–One of our most popular issues. The energy crisis is merely a prelude to what will surely come in the absence of efforts to husband nonrenewable resources while developing new ones. The seas offer great promise in this context. There is extractable energy in their tides, currents, and temperature differences; in the winds that blow over them; in the very waters themselves. Eight articles discuss these topics as well as the likelihood of finding oil under the deep ocean floor and of locating nuclear plants offshore.

MARINE POLLUTION, Fall 1974–Popular controversies, such as the one over whether or not the seas are "dying," tend to obscure responsible scientific effort to determine what substances we flush into the ocean, in what amounts, and with what effects. Some progress is being made in the investigation of radioactive wastes, DDT and PCB, heavy metals, plastics and petroleum. Eleven authors discuss this work as well as economic and regulatory aspects of marine pollution.

FOOD FROM THE SEA, Winter 1975–Fisheries biologists and managers are dealing with the hard realities of dwindling stocks and increasing international competition for what is left. Seven articles deal with these problems and point to ways in which harvests can be increased through mariculture, utilization of unconventional species, and other approaches.

DEEP-SEA PHOTOGRAPHY, Spring 1975–Out of print.

THE SOUTHERN OCEAN, Summer 1975–The first of a regional series (in planning are issues on the Mediterranean and Caribbean) examining important marine areas from the standpoint of oceanographic disciplines most interested in them. Physical, chemical, and biological oceanographers discuss research in antarctic waters, while a geologist looks at the ocean floor, meteorologists explain the effect of antarctic weather on global climate, and a policy expert sets forth the strengths and weaknesses of international scientific and political relations in the area.

SEAWARD EXPANSION, Fall 1975–We have become more sophisticated in our offshore activities than is generally realized. Eight articles examine trends in offshore oil production and its onshore impacts; floating oil ports; artificial islands; floating platforms; marine sand and gravel mining. National and local policy needs are examined in the light of the move seaward.